Cherenkov Telescope Array: the future of ground-based gamma-ray astronomy

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Current IACTs

Status and Technology

Current IACT key players

VERITAS (Arizona, USA)

Array 4 telescopes of 12m diam.
Central mast mounting
1800 m asl
>2007

Array 2 telescopes
17m diameter
2200 m asl
>2004

MAGIC (Canary Islands, Spain)

H.E.S.S. (Namibia)

HESS I: Array 4 tel. of 12m
HESS II: 28m diameter (>2010)
1800 m asl
> 2003

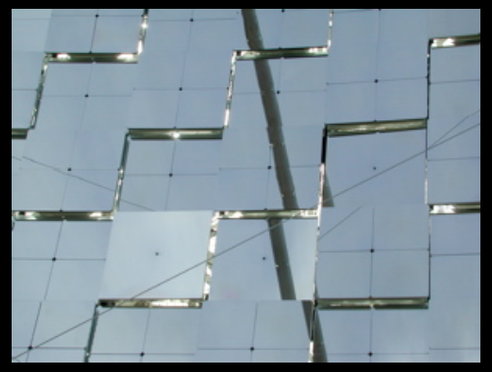
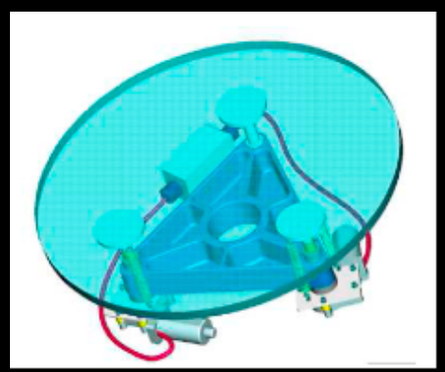
Well-proven technology...

Mount

- Alt-azimuth mount
- Central mast or circular rail
- Spherical or parabolic reflector
- experience: 12-17m diameter

Well-proven technology...



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Mirror

- Tessalated surface
- Extreme optical precision not required
- Solid glass, aluminum, glass-aluminum replica

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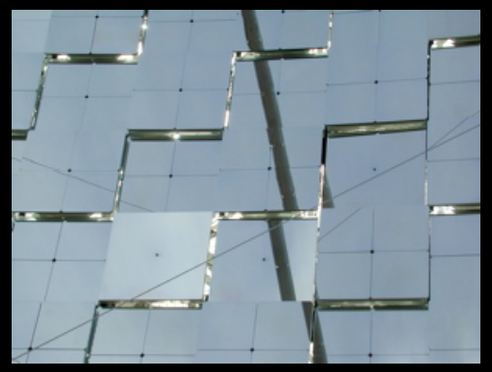
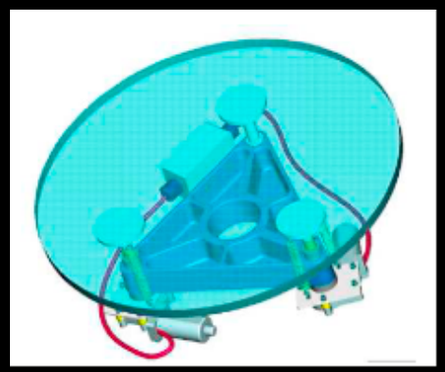

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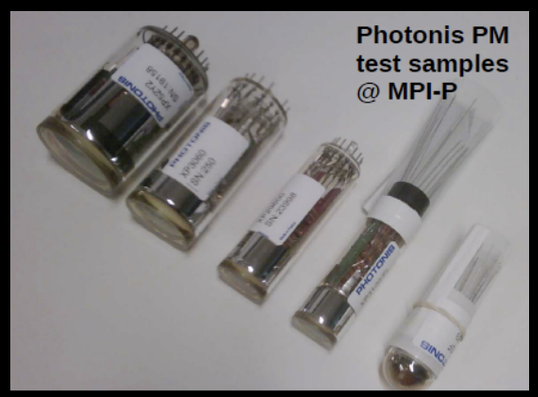

Camera

- ~1000 pixels
- Photomultipliers (presently...)
- most expensive part of the telescope

Well-proven technology...



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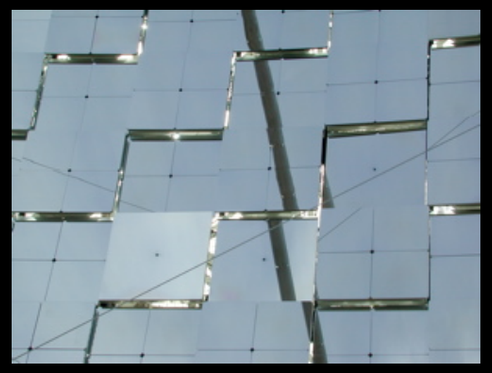
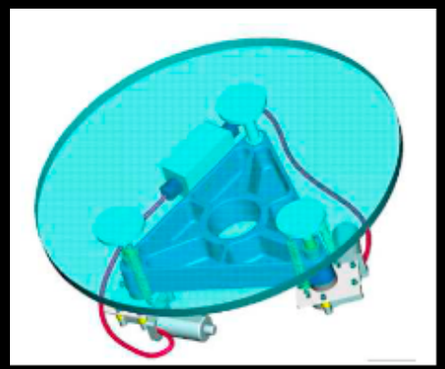

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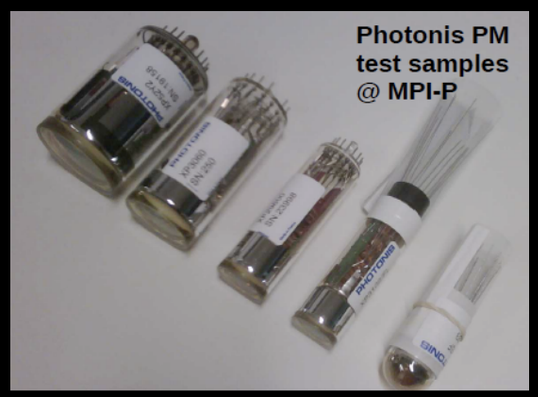

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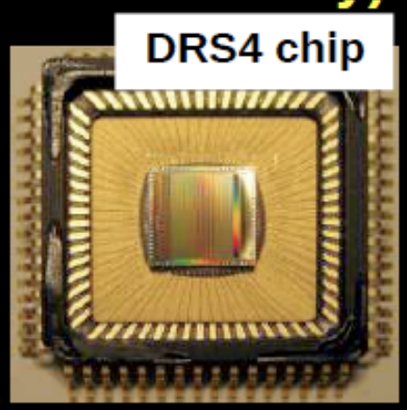


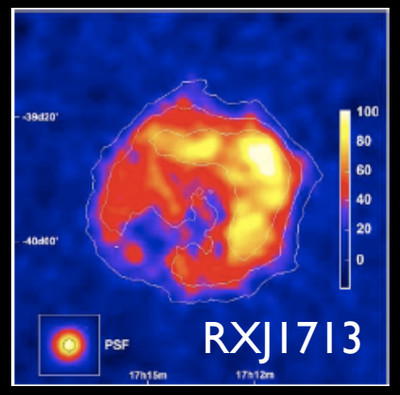
Electronics/trigger

- Cherenkov signal lasts few ns, fast electronics
- Tbytes/night
- Topological triggers for single telescopes
- Central trigger for stereoscopy

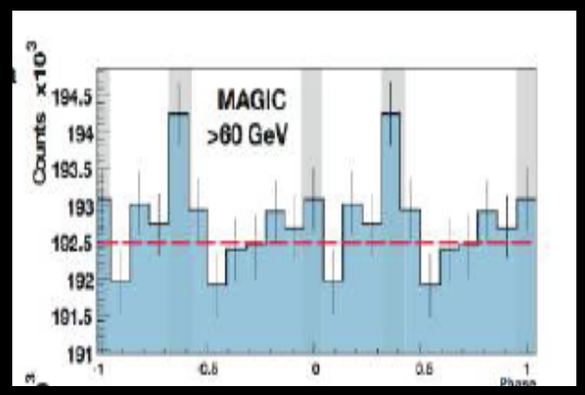
...and guaranteed scientific outcome

Recent reviews: Hinton 07, Horns 08, Aharonian+08, De Angelis+08

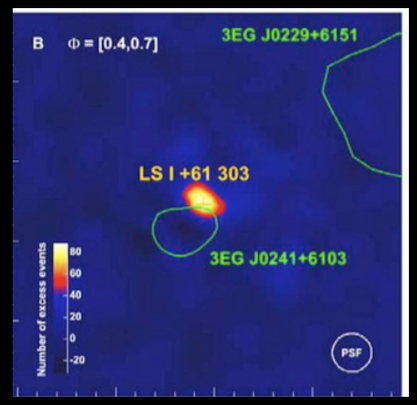
- Galactic gamma-ray sources



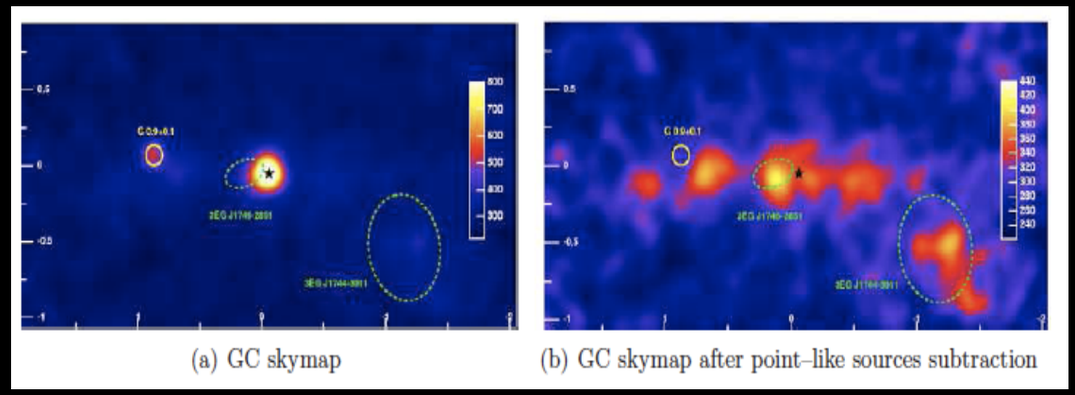
γ-morphology SNR



Pulsed γ from pulsars

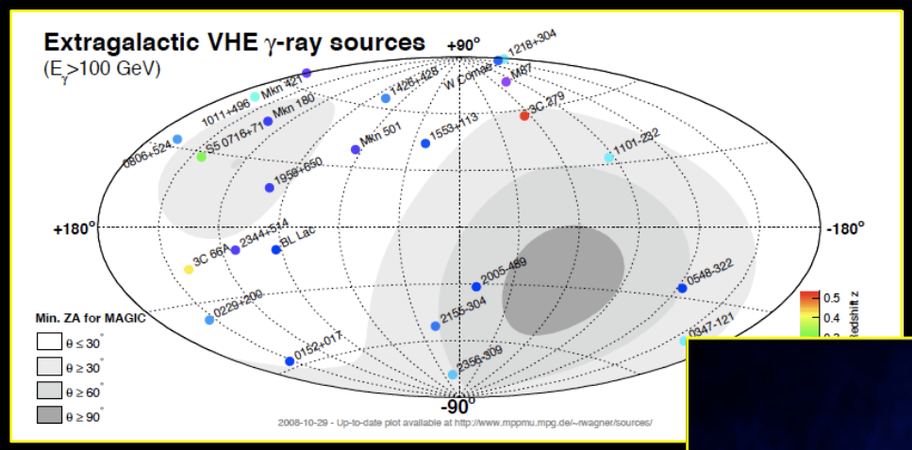


Periodic γ from binaries

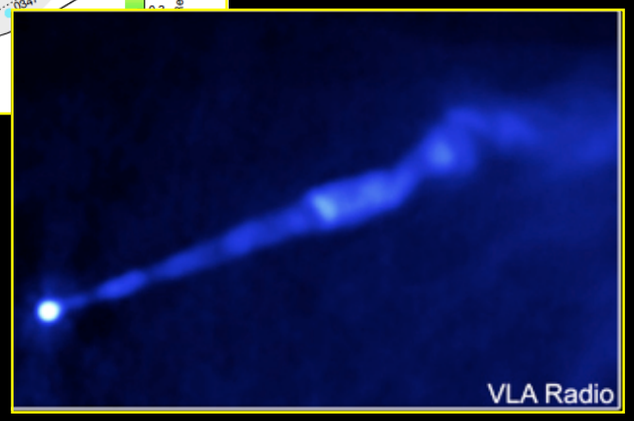


Diffuse and pointlike γ from GC

- Extragalactic gamma-ray sources



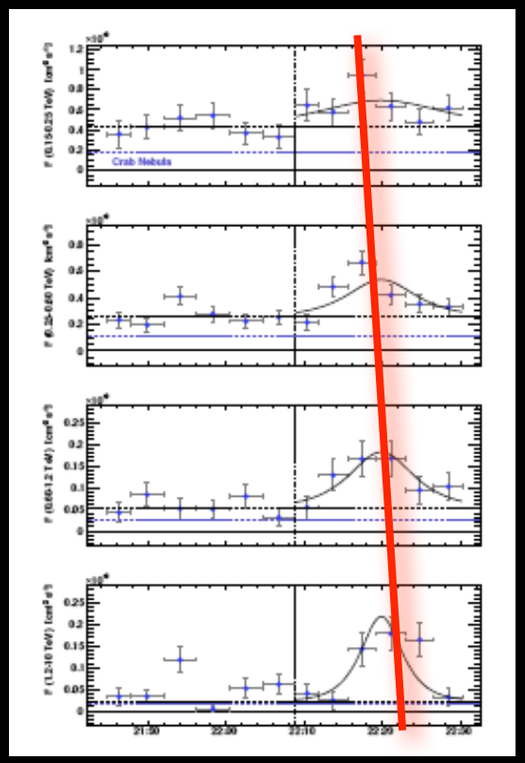
Growing catalog of blazars



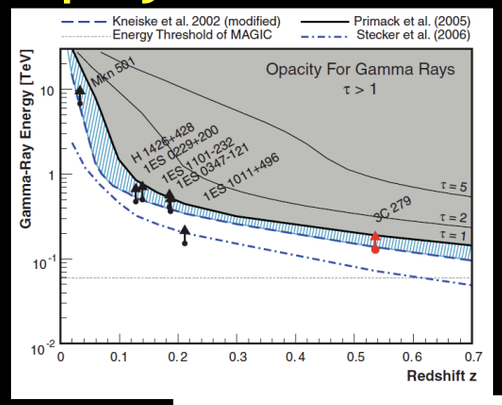
radiogalaxies M87,
Centaurus A

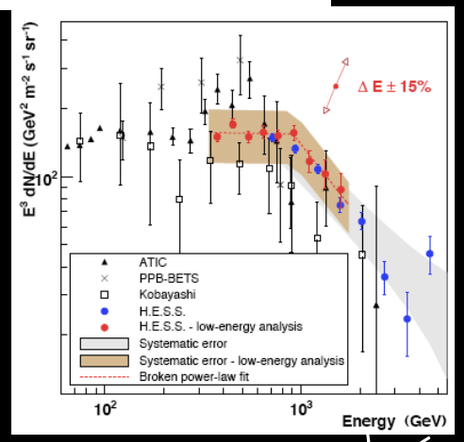
- Fundamental/CR physics

Transparency



Delay vs energy





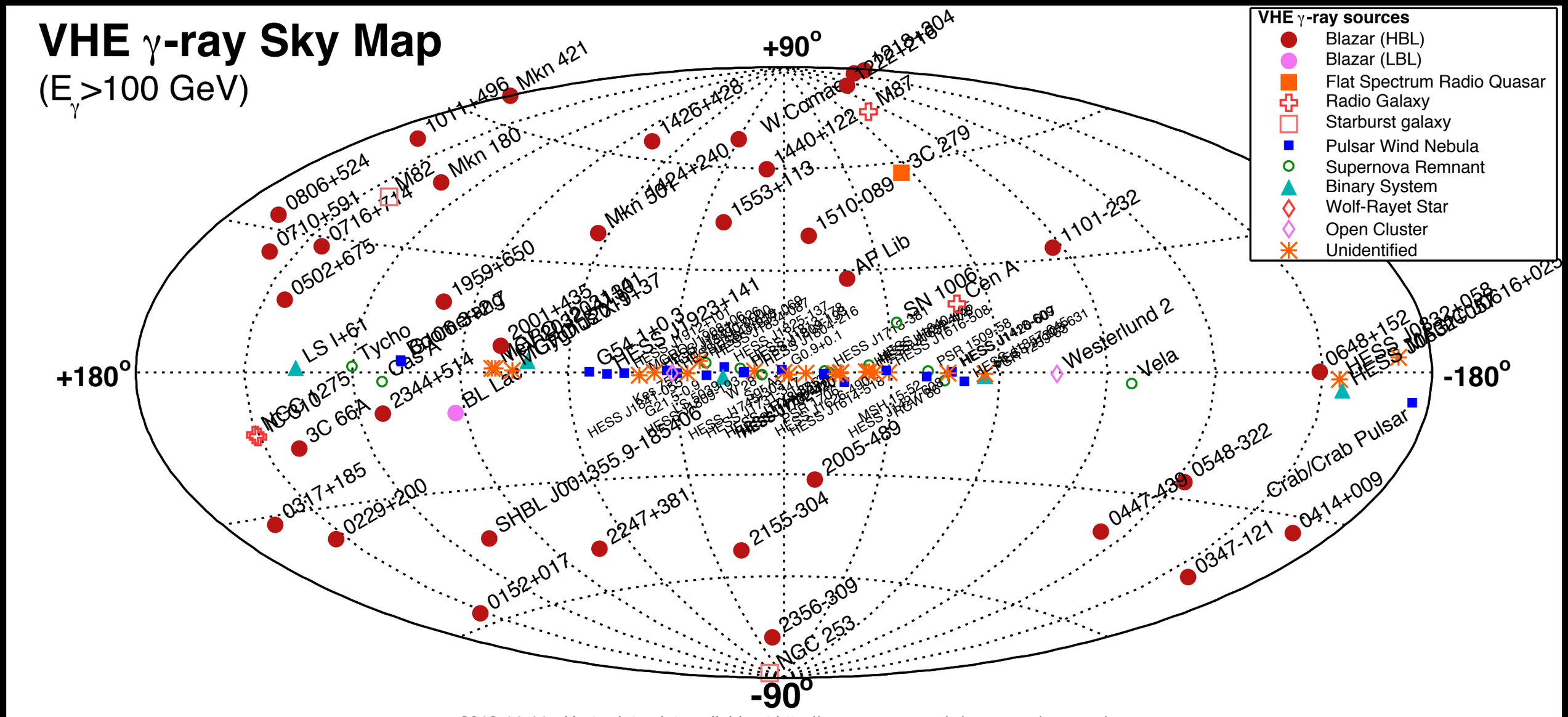
Electron-Positrons

Current Status

- H.E.S.S., MAGIC, VERITAS
- Regular observations between <50 GeV and >20 TeV
- Few % Crab sensitivity
- The current generation of telescopes have detected > 115 sources
- Well above 100 sources likely with HESS 2, MAGIC II, VERITAS

- Stellar Winds
- Supernova Remnants
- Pulsar Wind Nebulae
- Binary Systems
- Molecular Clouds
- Galactic Centre
- No Counterpart/Dark Sources
- AGN
- Constraints on EBL
- Constraints on QG
- CR Electron Spectrum

A dynamic field of astrophysics



2010-11-11 - Up-to-date plot available at http://www.mpp.mpg.de/~rwagner/sources/

Science Potential

adapted by Hinton from Horan & Weekes 2003

Distance kpc Mpc Gpc

SNR/PWN

Pulsed

Binaries

Radio Galaxies

Blazars

Current Sensitivity

CTA

Colliding Winds

Starbursts

Clusters

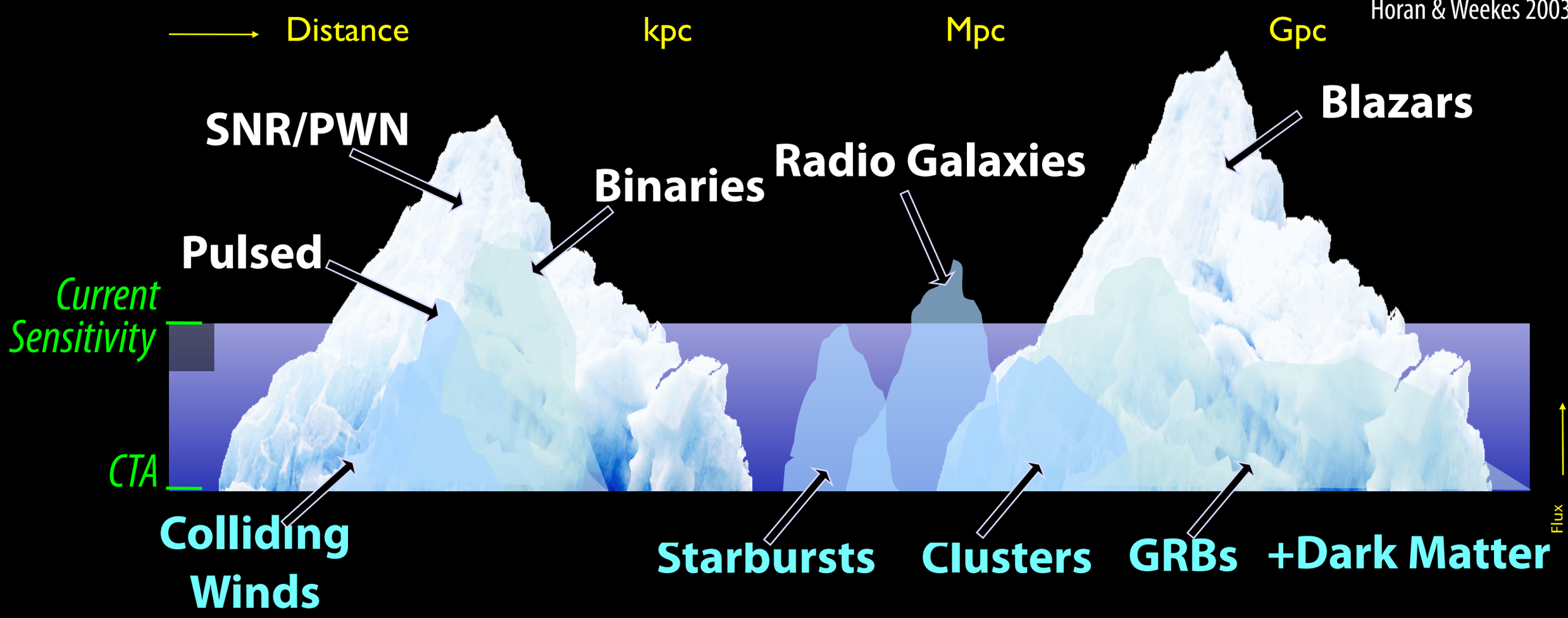
GRBs

+Dark Matter

Flux

Science Potential

adapted by Hinton from Horan & Weekes 2003



- Current instruments have passed the critical sensitivity threshold and reveal a rich panorama,
  but this is clearly only the tip of the iceberg

Science Potential

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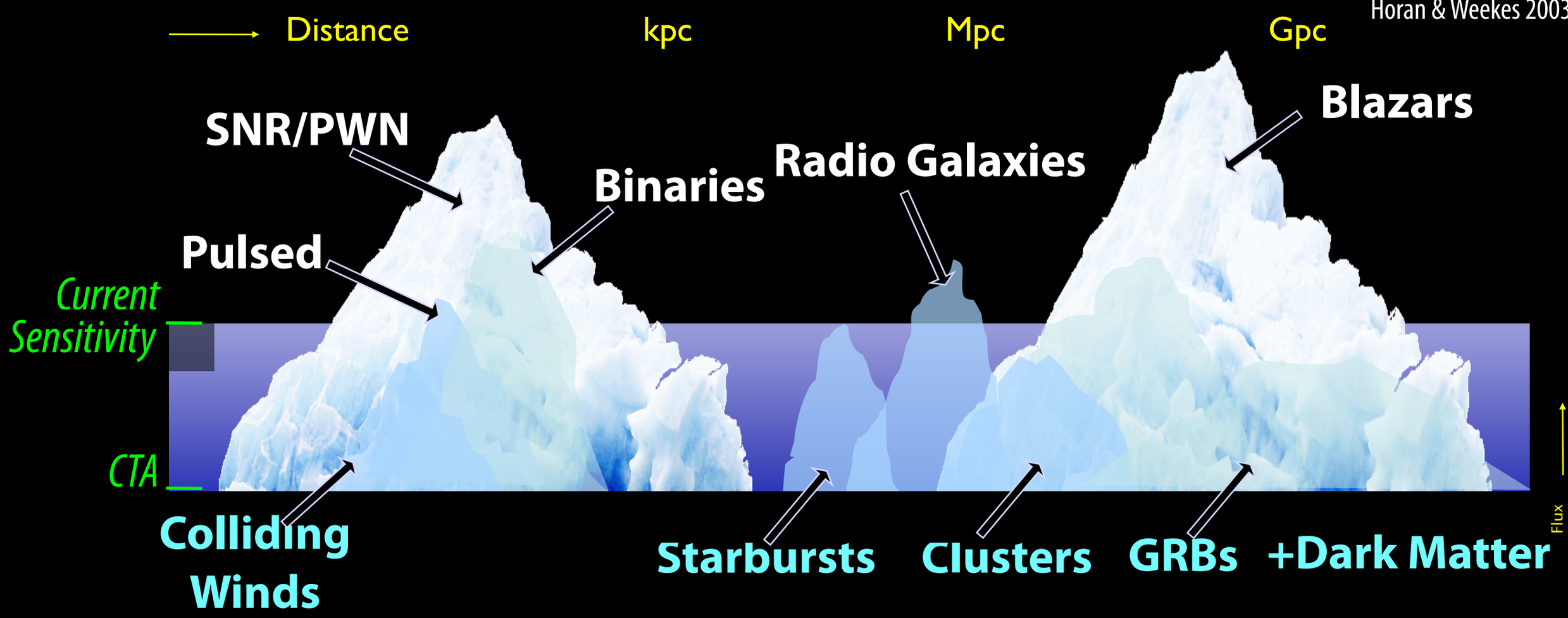
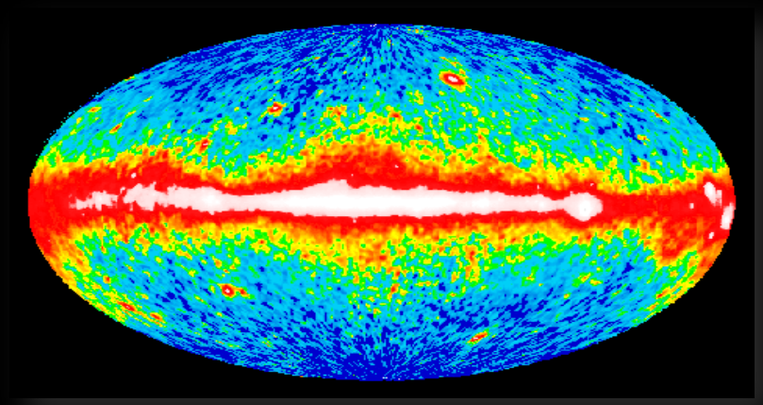
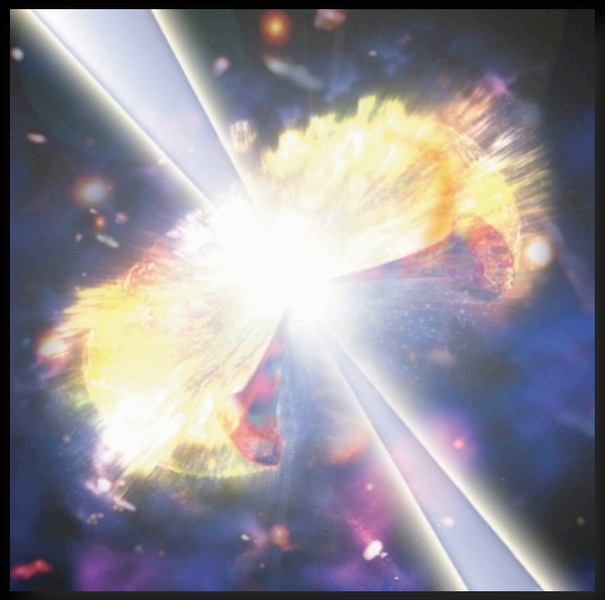


- Current instruments have passed the critical sensitivity threshold and reveal a rich panorama, but this is clearly only the tip of the iceberg
- With CTA we expect to detect and study > 1000 sources in great detail

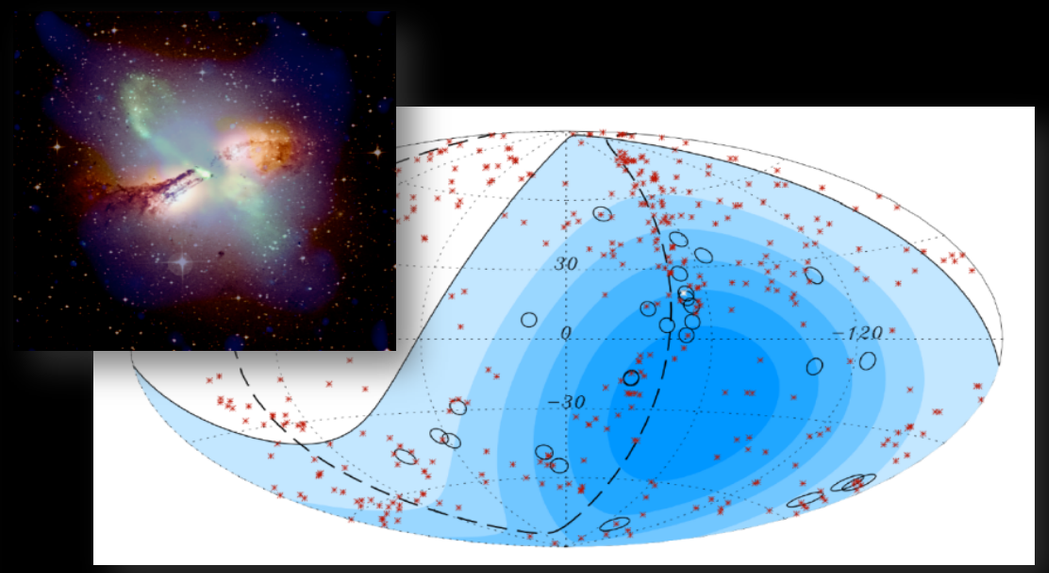
Possible New Classes of Sources in CTA



Galactic Diffuse



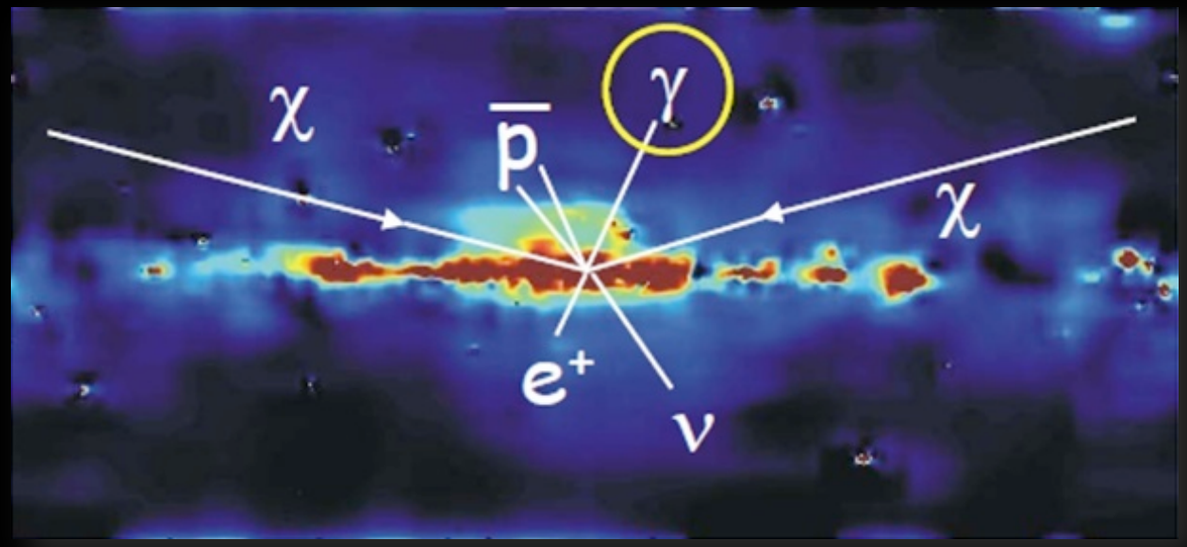
GRBs



UHECR Sources

Starburst galaxies
Galaxy mergers

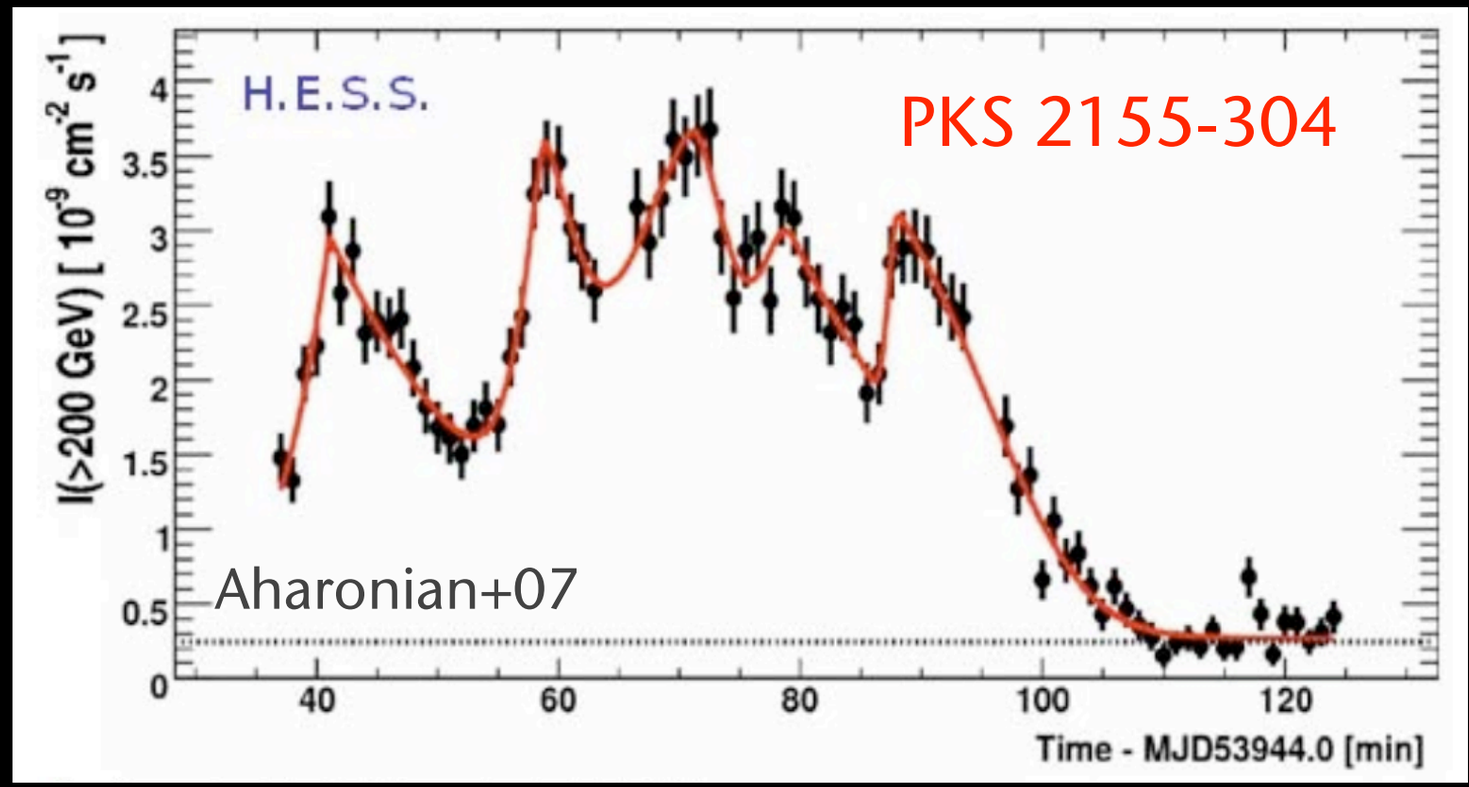
Clusters of galaxies

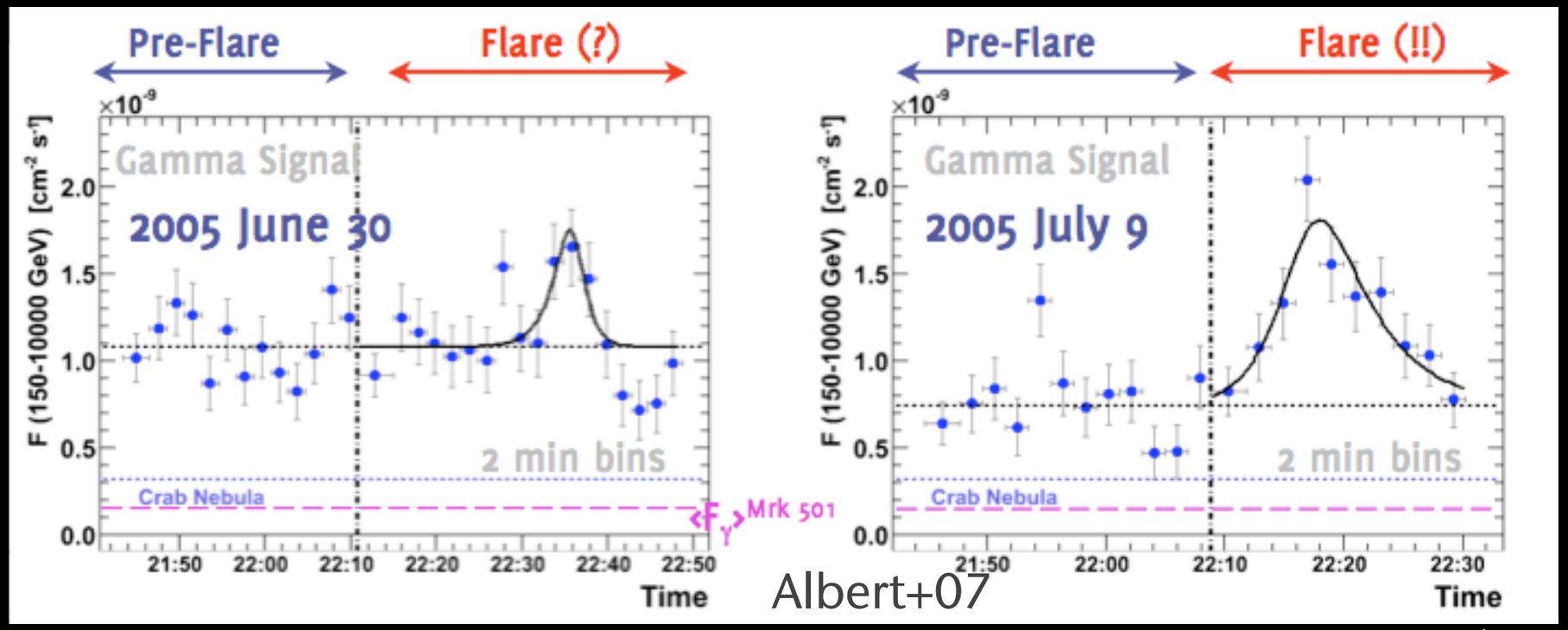


Dark Matter Annihilation

A key advantage of IACT

- CTA will resolve finest details and reveal shortest flux variability time scales
  Time resolved multiwavelength studies
- With CTA we will be able to measure accleration and cooling time scales
- Hard limits on quantum gravity scale
  HESS/MAGIC: 0.02 M_p
  --> CTA: O(0.1 M_p), max. O(x70) better





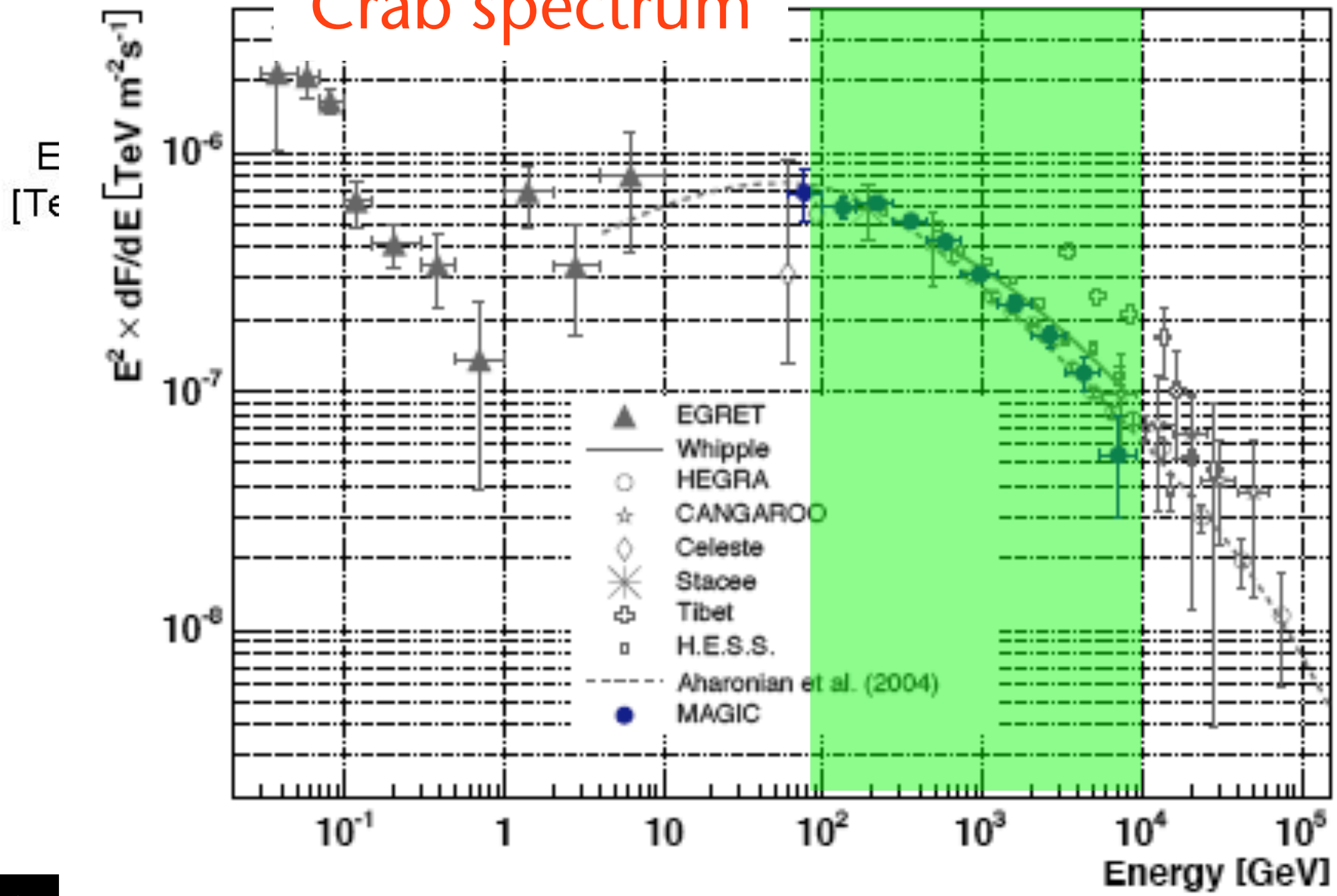
review: RMW,
AIP Conf. Ser 1112

Towards a precision gamma-ray astronomy

Physics motivations

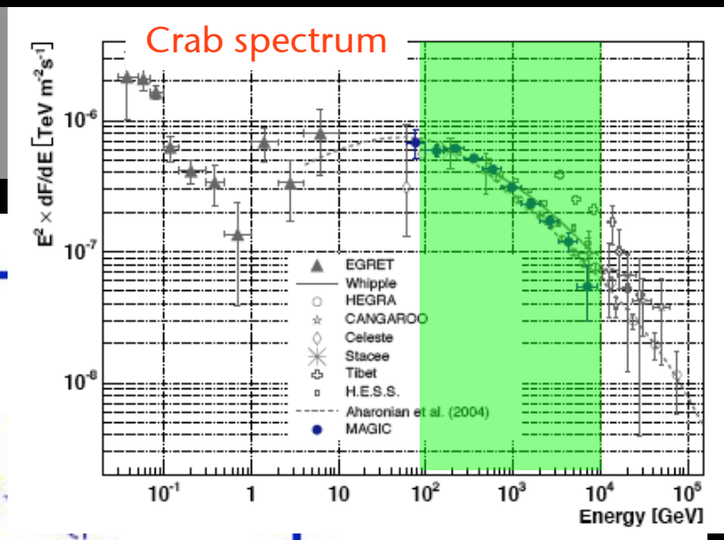
CTA sensitivity

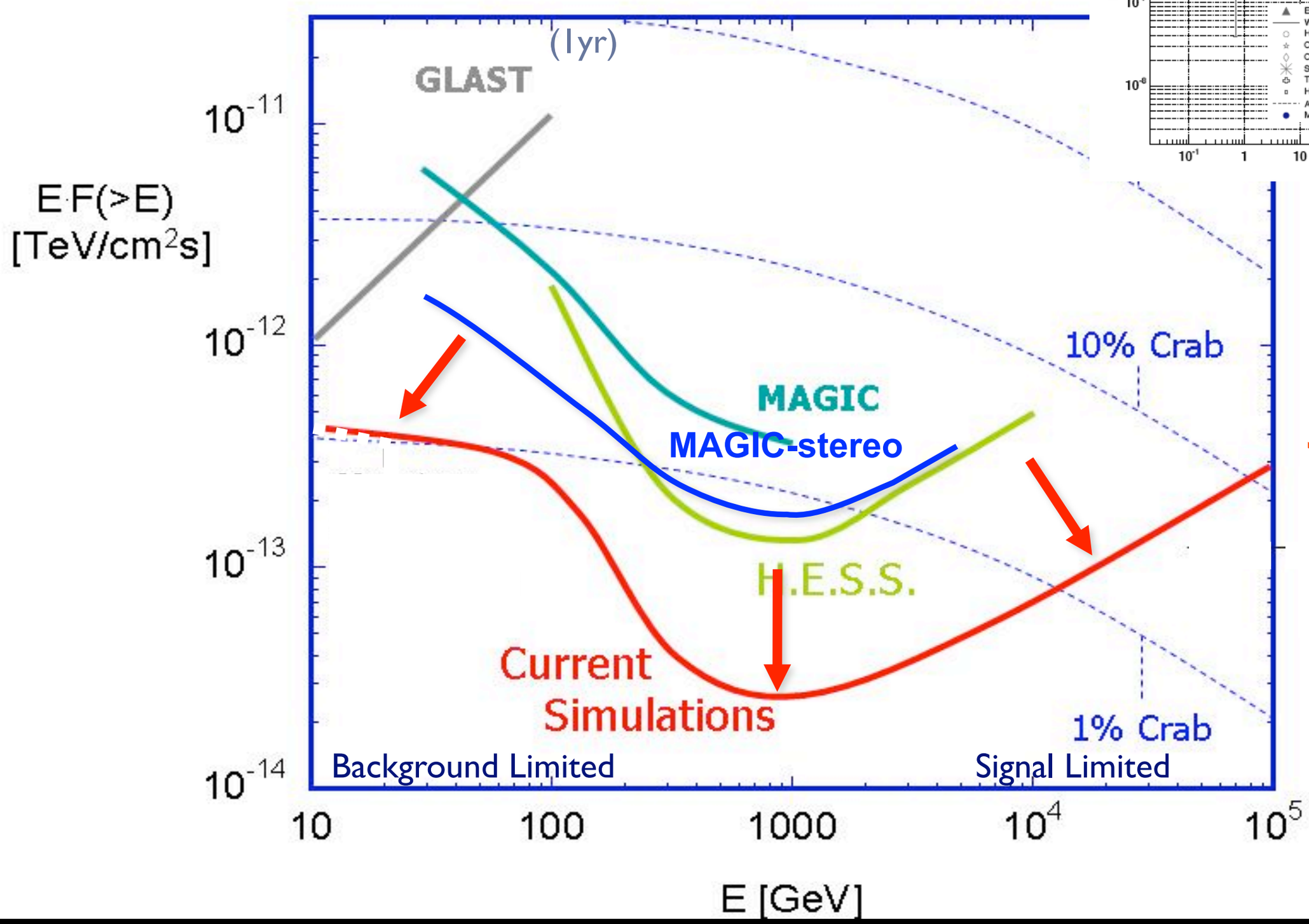
Crab spectrum



rs

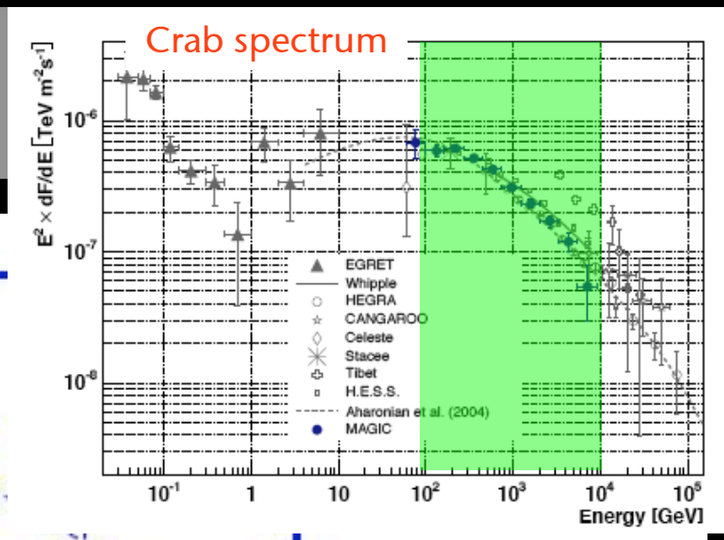
CTA sensitivity





50hrs

CTA sensitivity



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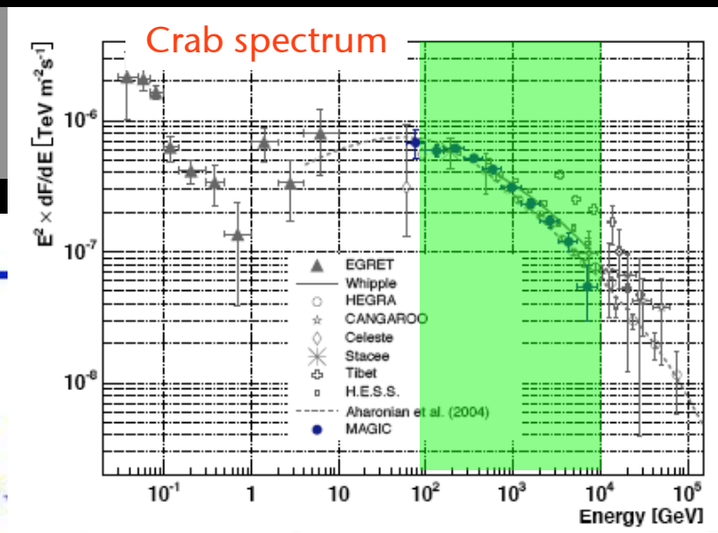
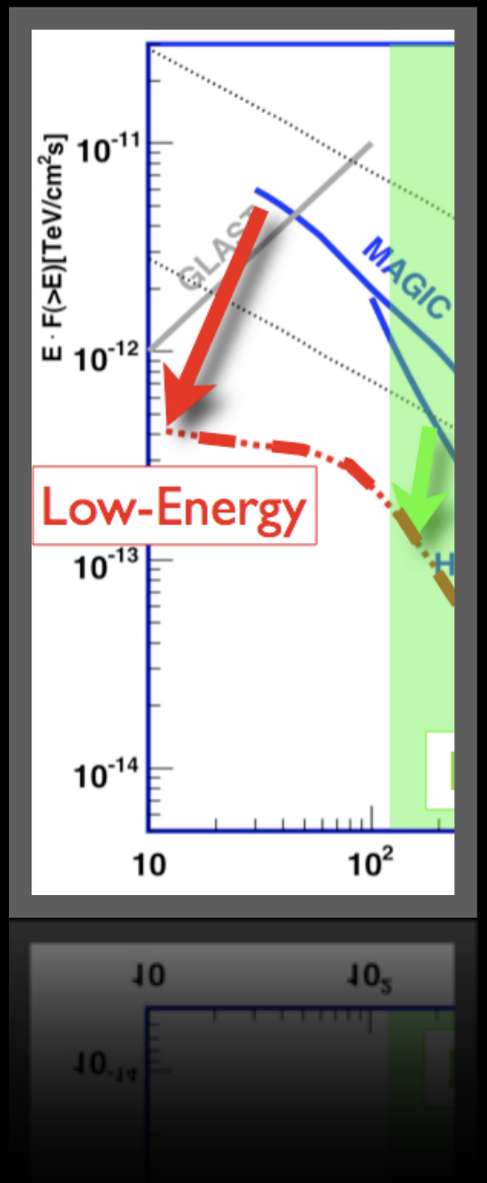


The low energies <50 GeV



Galactic objects

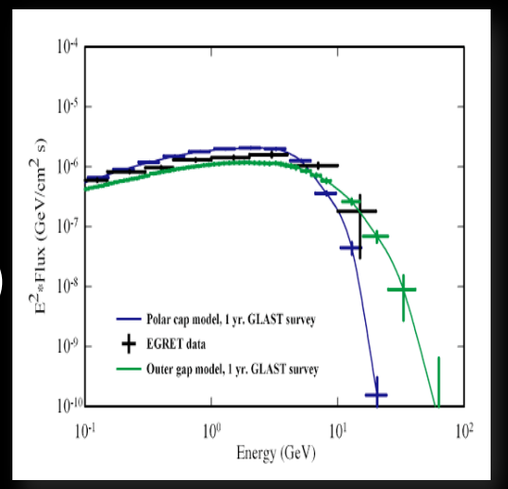
- Investigate Pulsar models: pulsars have cutoff (below ~60 GeV) dependent on acceleration model (close or far from surface)
- Synchrotron emission from PWNs: PWNs may emit synchrotron ~50 GeV gamma-rays from ultra-relativistic winds
  - Investigate acceleration mechanisms
- hadronic/leptonic acceleration at SNRs: there are substantial spectral differences below 100 GeV

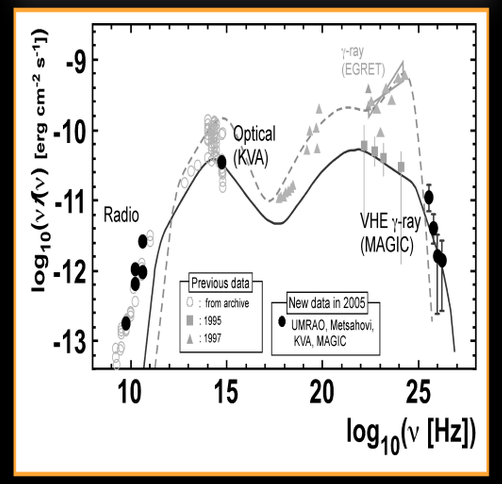
Extragalactic objects

- Steep-spectrum blazars.
- Complete Fermi-LAT source catalog at VHE

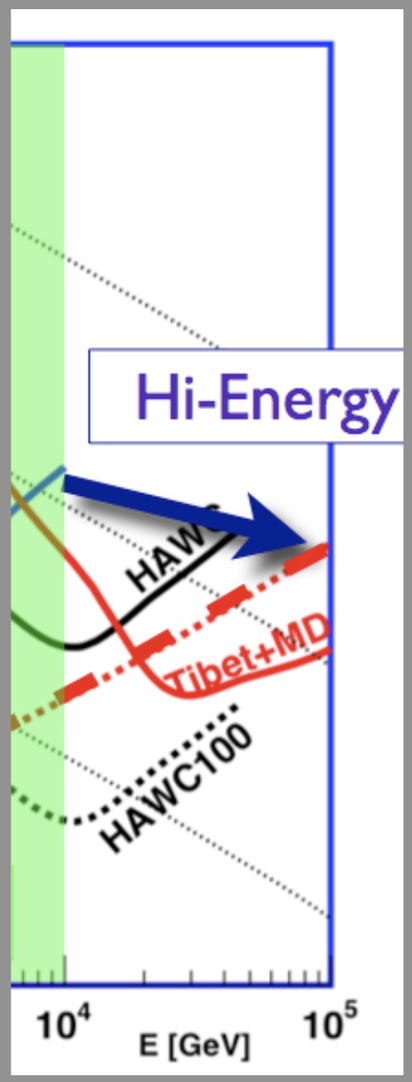
Other

- overlap with Fermi-LAT on all unidentified >GeV sources
- increase probability of observation of low-mass DM candidates

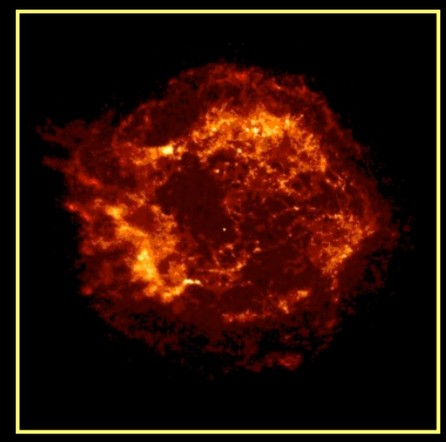




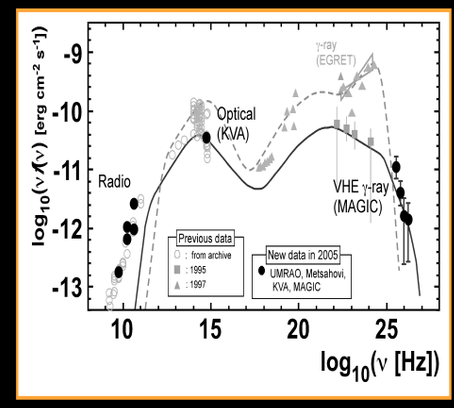
High energies: statistics



- Galactic sources
  - Acceleration mechanism in SNRs (again): Above 50 TeV, hadronic/leptonic acceleration mechanism at SNRs differ
  - the nature of ultra-relativistic jets of microquasars
  - the nature of binary systems



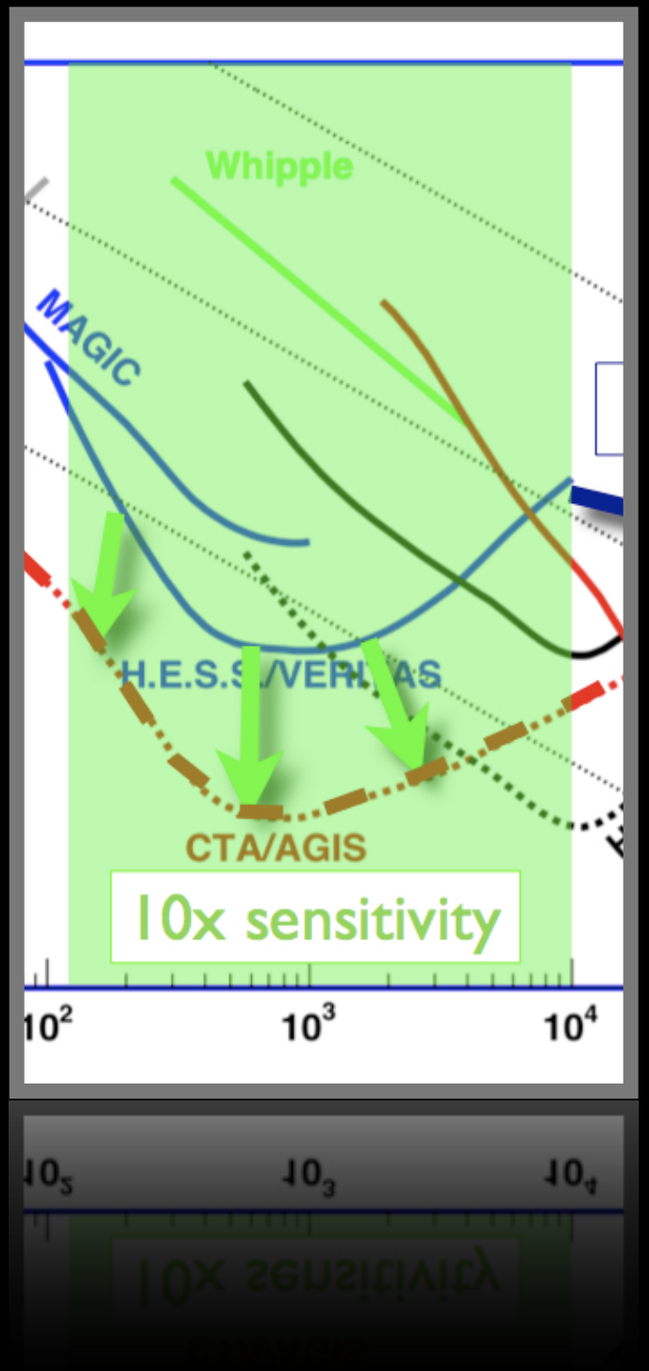
Supernova Remnants



- Extragalactic sources
  - Extragalactic Background light
  - Precision measurement of intrinsic cutoffs in nearby sources

- Other
  - Lorentz invariance delays between HE/LE photons
  - Probing the knee in cosmic-ray spectrum

Improve sensitivity

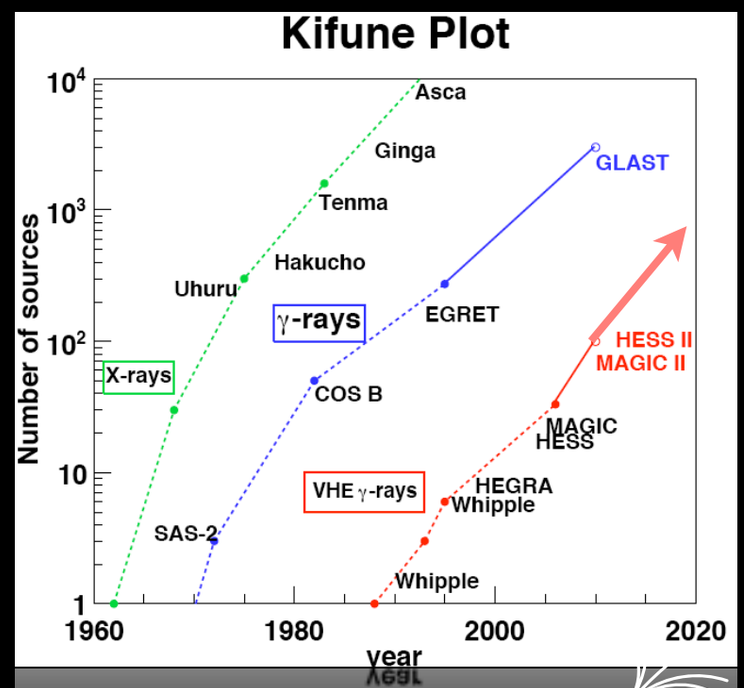


- The most obvious improvement
- leading to precision VHE TeV astronomy

Morphological studies on galactic targets
- local interaction with gas/matter
- discrimination hadronic/leptonic mechanisms
- interaction with globular clouds

Variability studies
- sub-min scale variation (pulsar, binaries, AGNs,Lorentz invariance)
- possibility to make follow-up obs. (binaries,blazar)

Consolidate TeV astronomy
- ~1000 new sources expected
- acceleration sites of extragal. CRs (galaxy mergers, galaxy clusters, IR galaxies, ...)
- VHE emission model for AGNs
- GRBs...

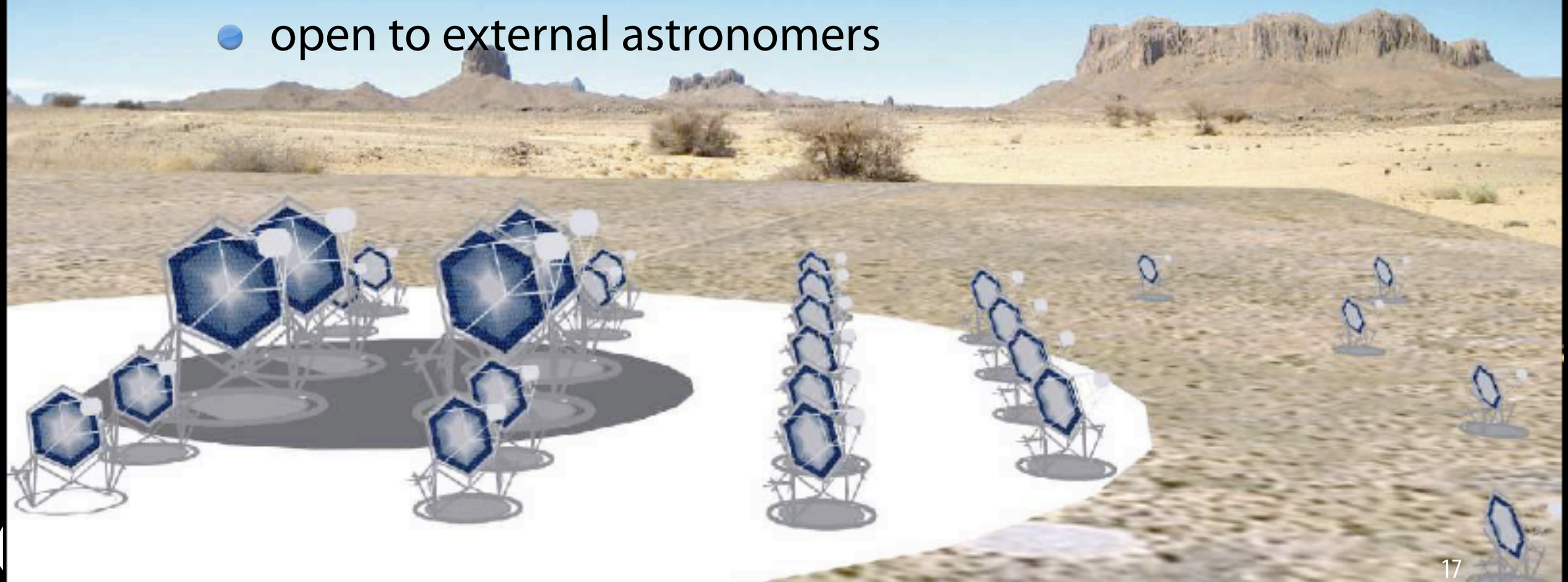


CTA

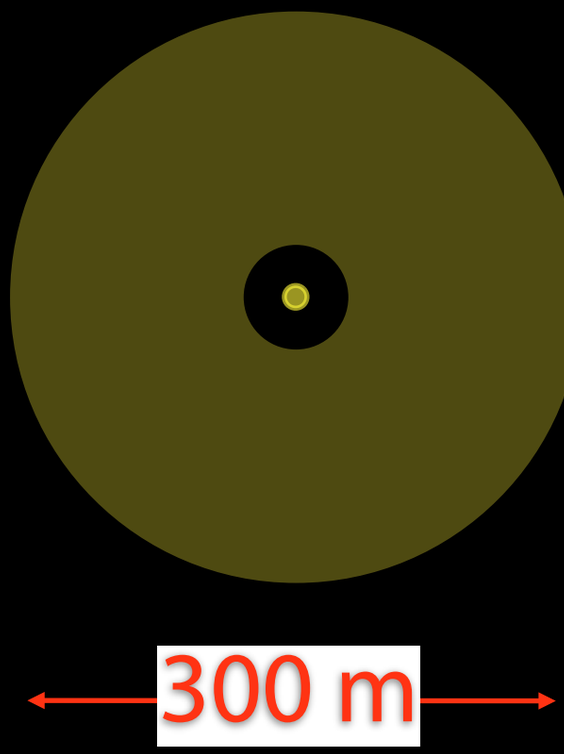
Technical demands

General design

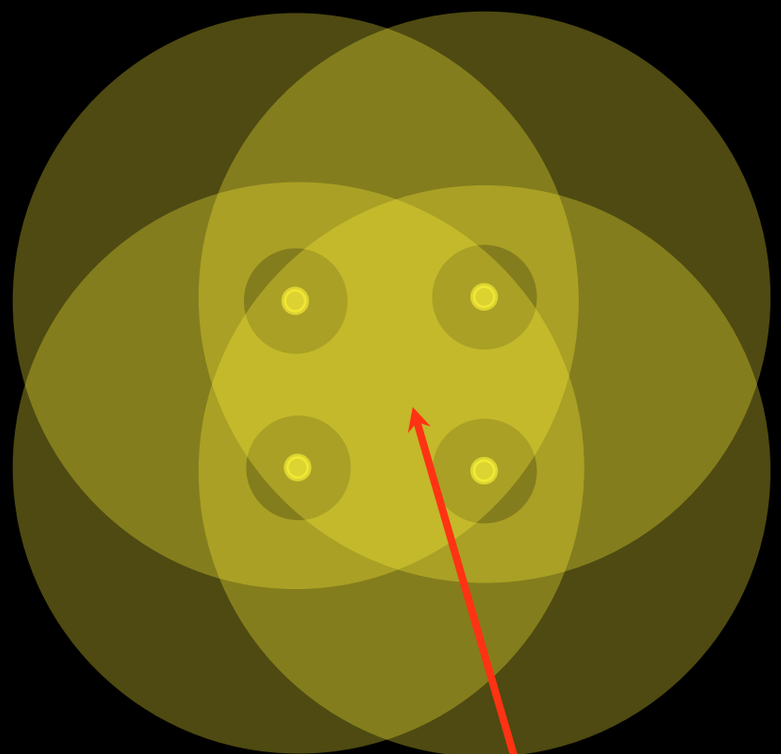
- DESIGN
  - Increase array from 4 to ~ 100 telescopes
  - Distribute them over large area (~1 km^2)
  - telescopes of 2-3 different sizes
- DEVELOPMENT
  - Use well-proven technology of current IACTs
  - High automatization
- OBSERVATORY
  - open to external astronomers



Why an array?

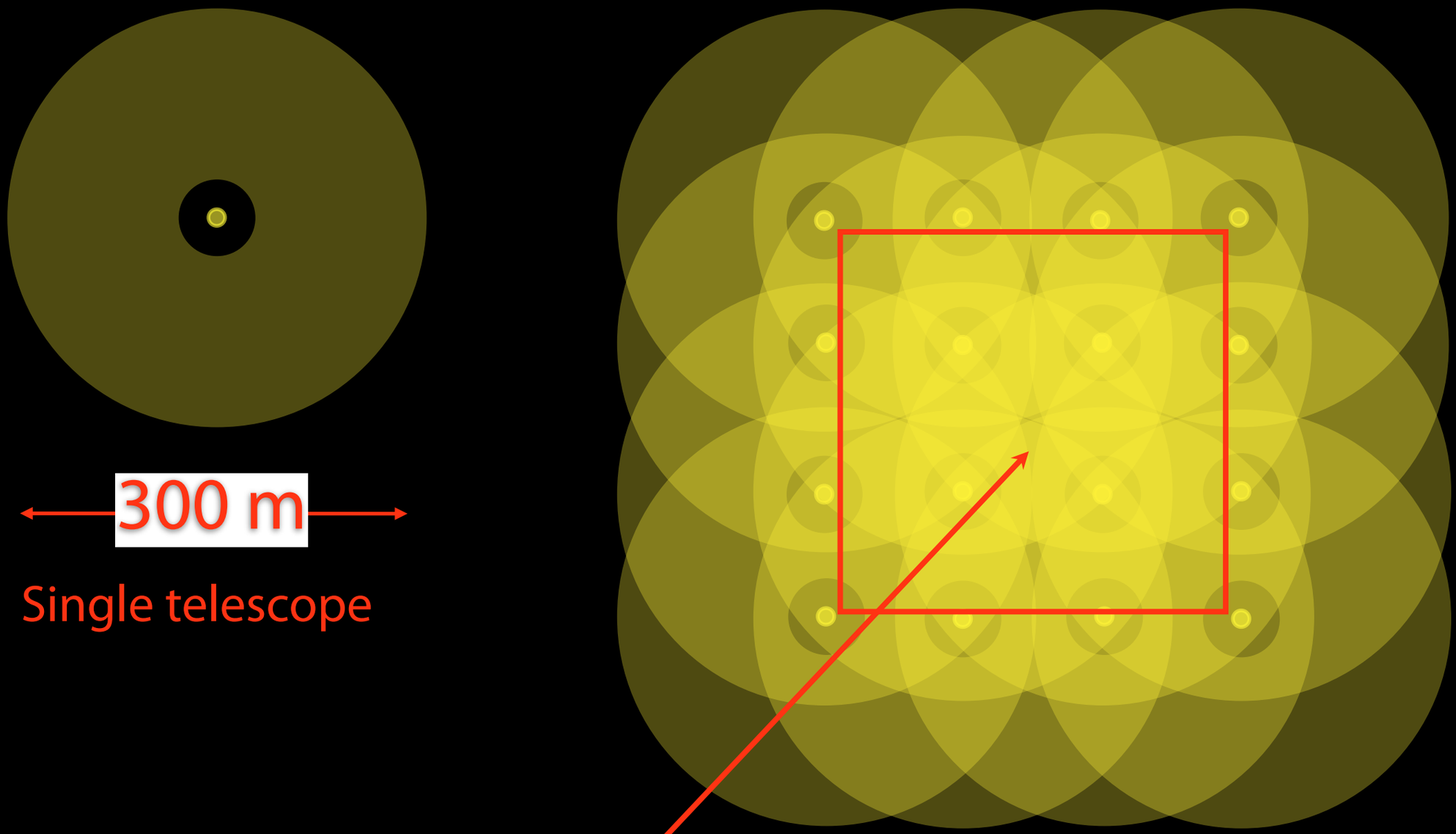


Single telescope



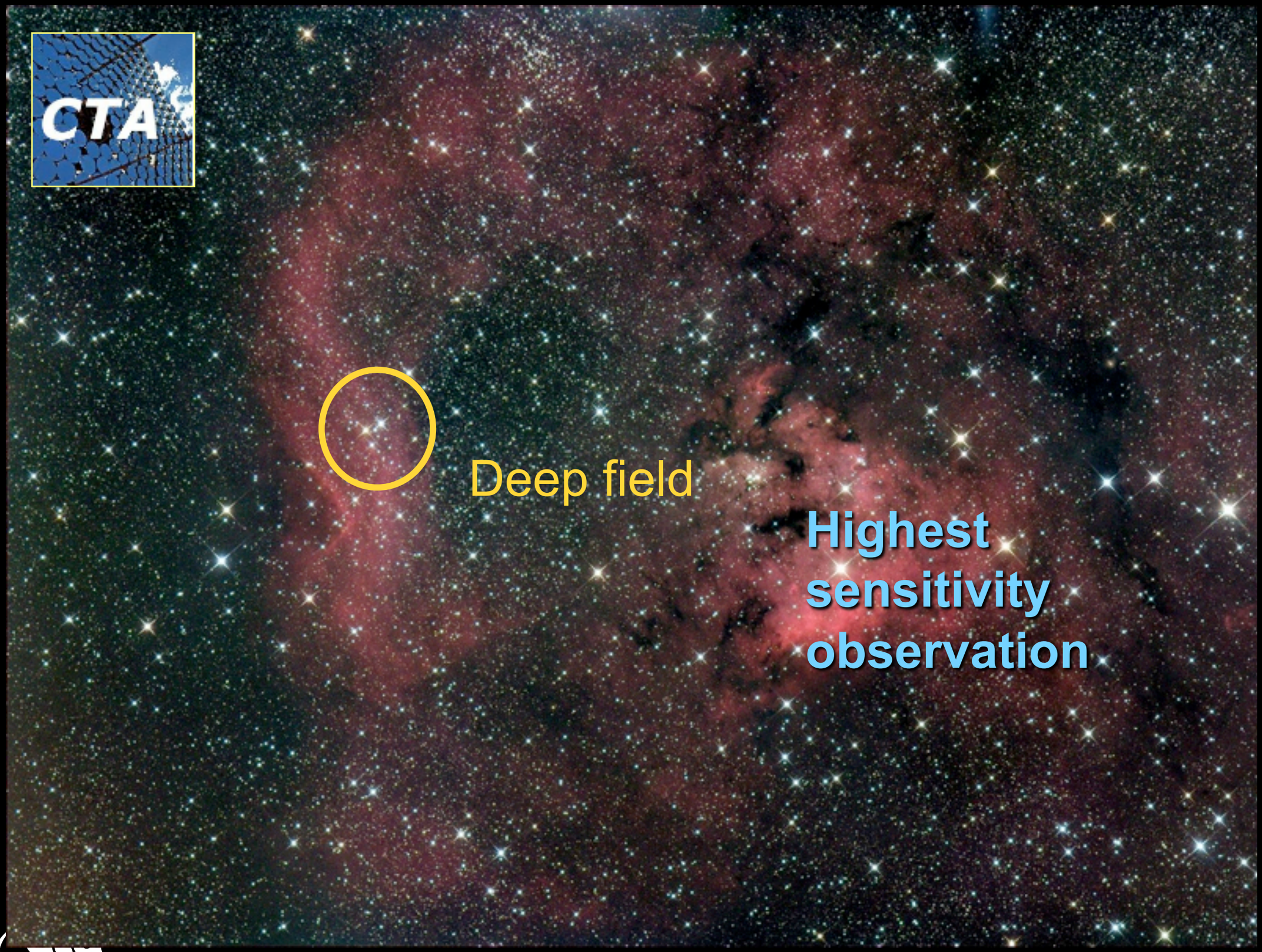
High sensitivity, small region

Why an extended array?



Observation modes

Observation modes



Observation modes

1/3 array
Deep field

1/3 array
Deep field

1 telescope
Monitor

4 telescopes
Monitor

Permanent monitoring of some AGN

--> ToO-triggers on huge flares

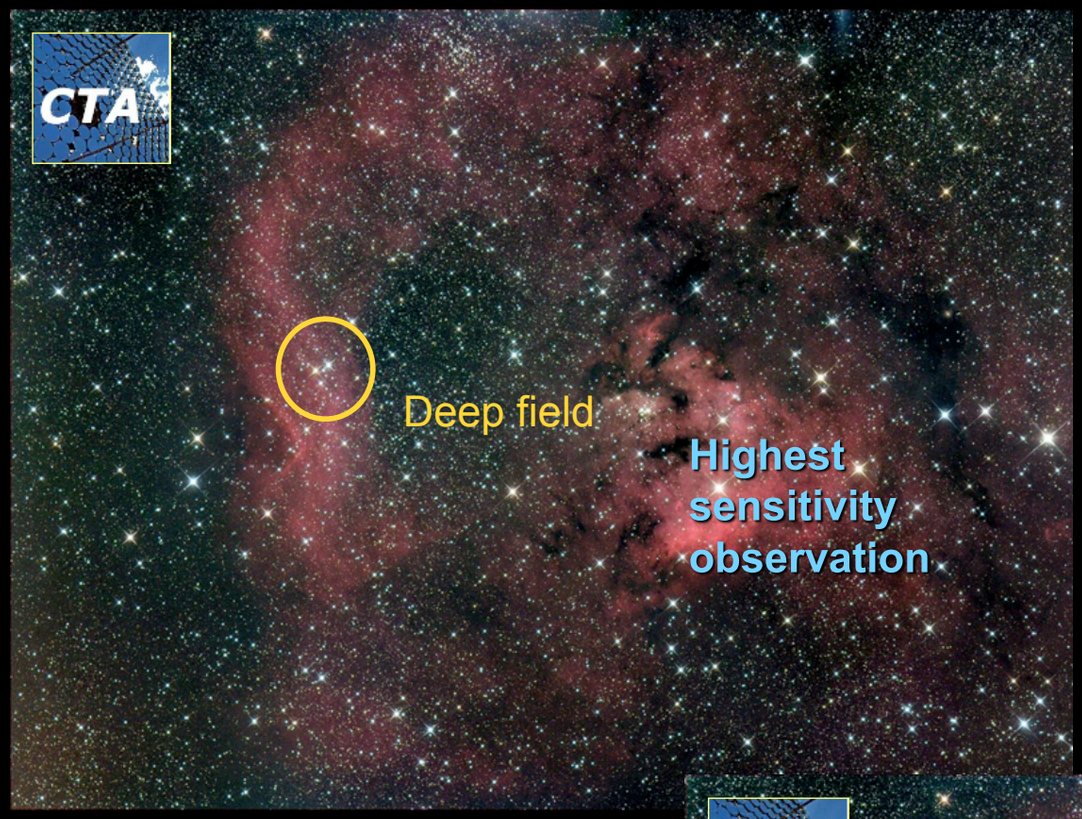
Observation modes

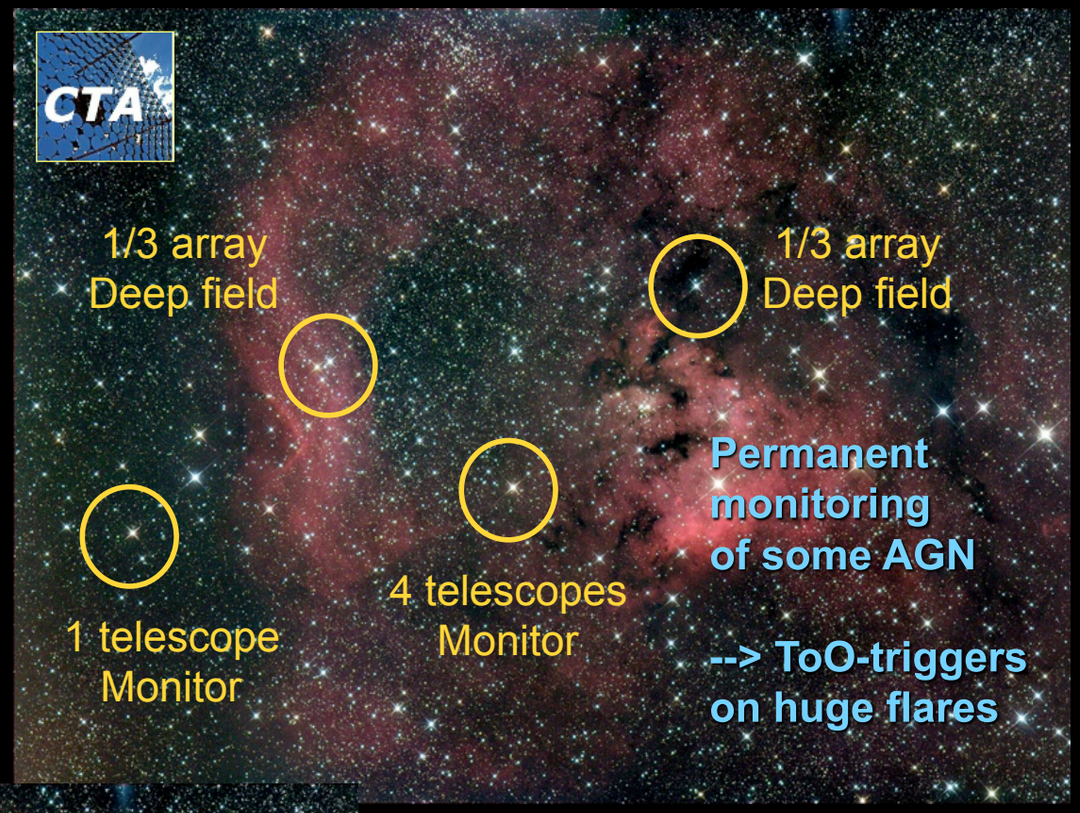
Wide FOV Scan

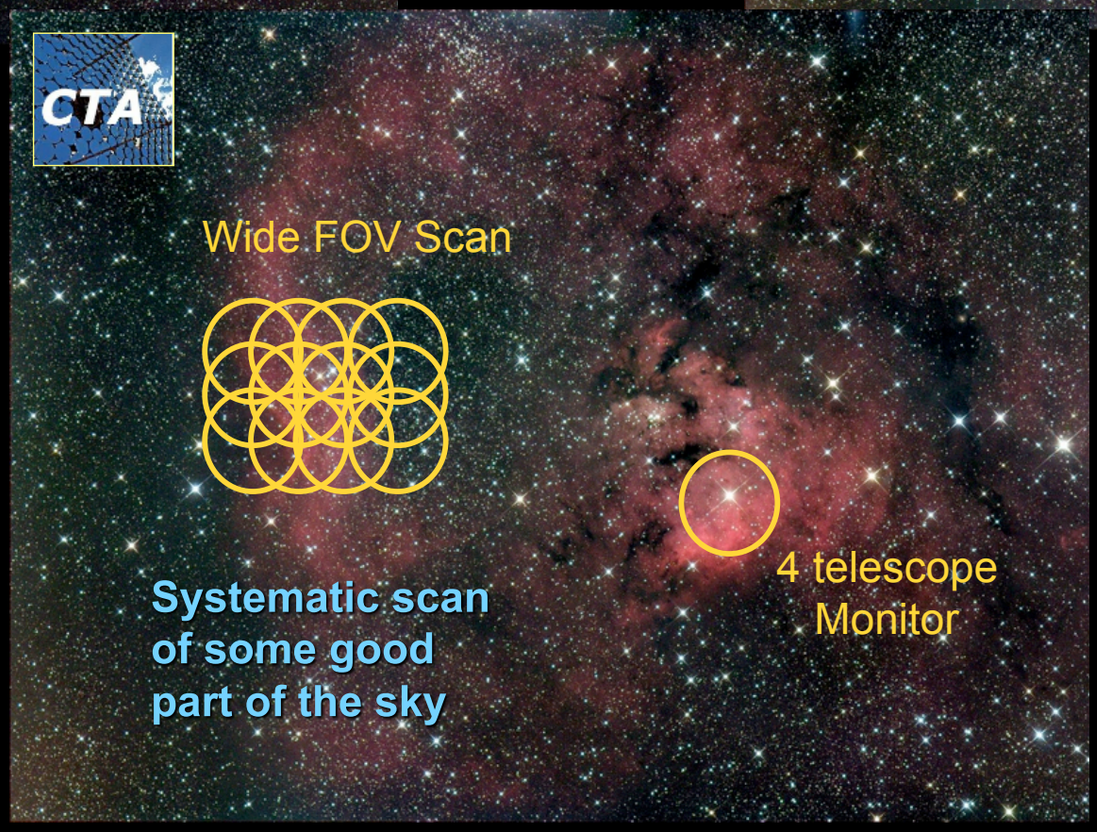
Systematic scan of some good part of the sky

4 telescope Monitor

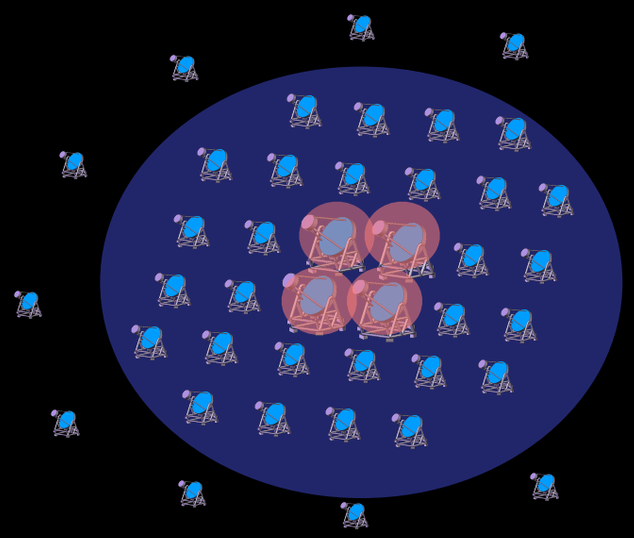
Observation modes







Concept



- Few Large Size Telescopes
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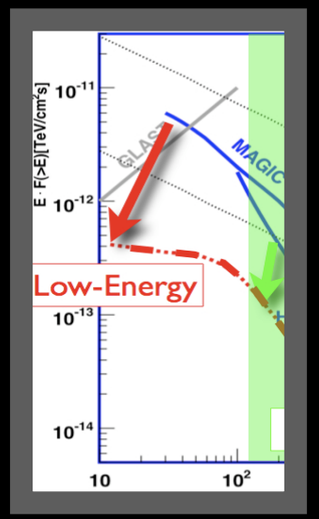
  - Large reflective area
  - Parabolic profiles to maintain shower timing
  - Challenging technology in many aspects
  - Restricted FOV (~3.5°)



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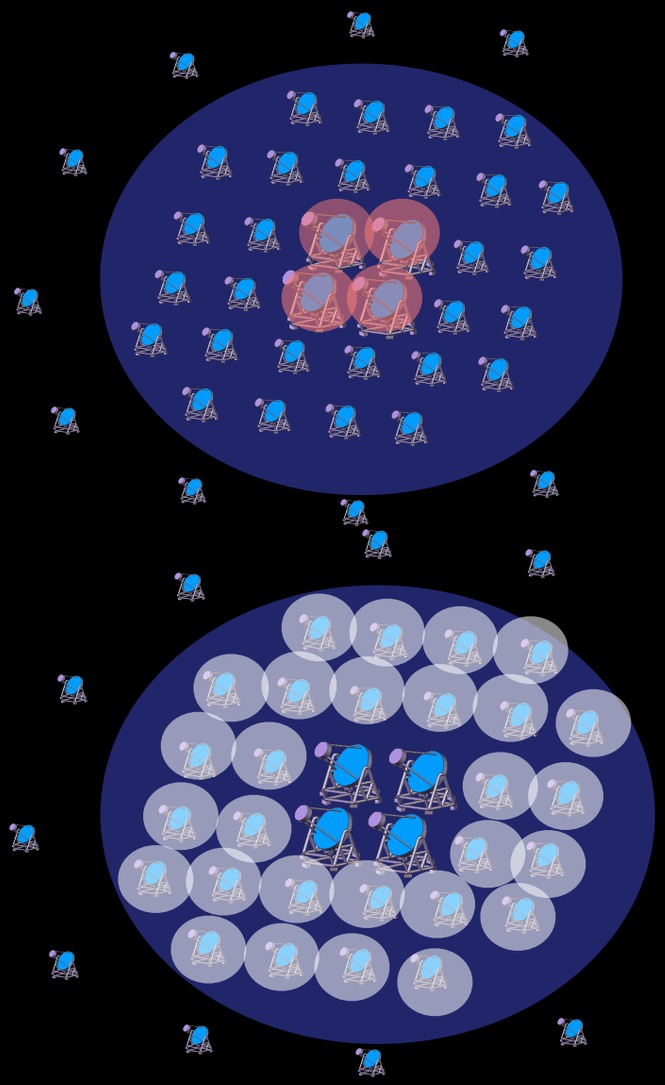

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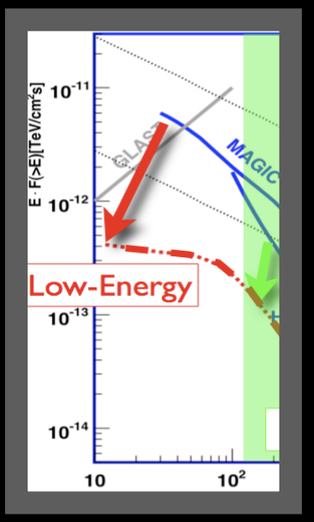
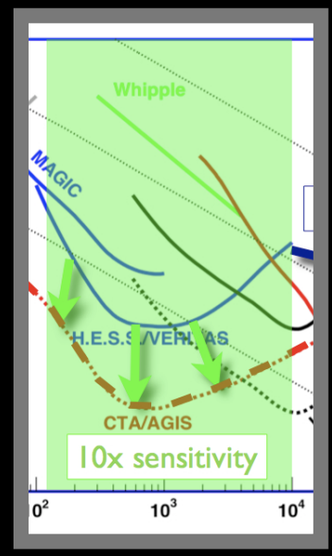
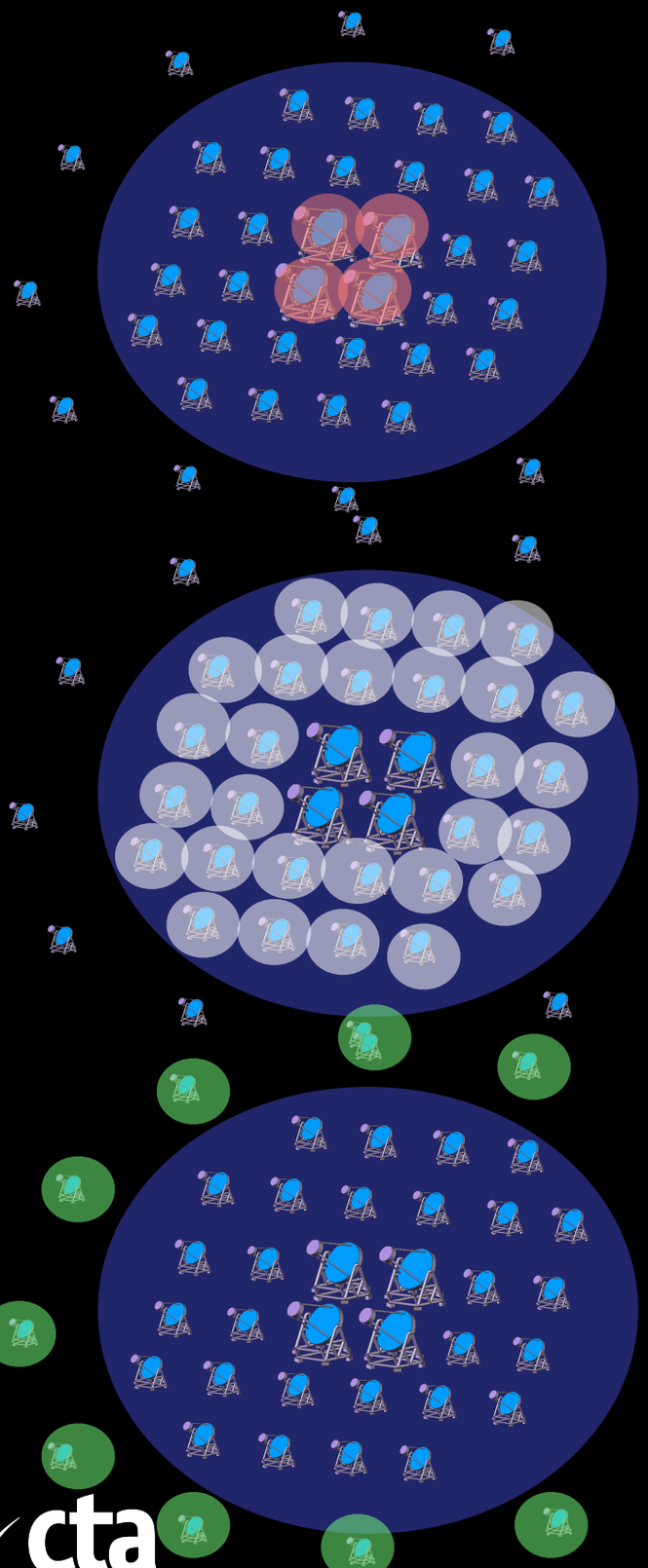


- Several Medium Size Telescopes perform
  100 GeV-50 TeV detection
  - well-proven technology (HESS, MAGIC)
  - goal is to reduce costs and maintenance
  - core of the array
  - may act as veto for LSTs



Concept



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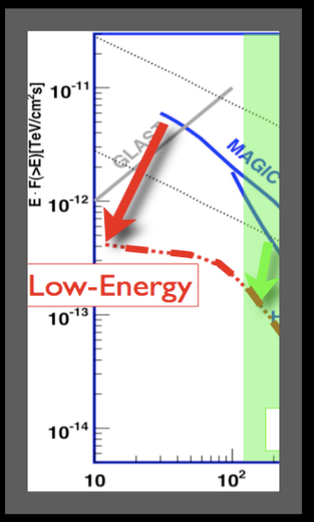

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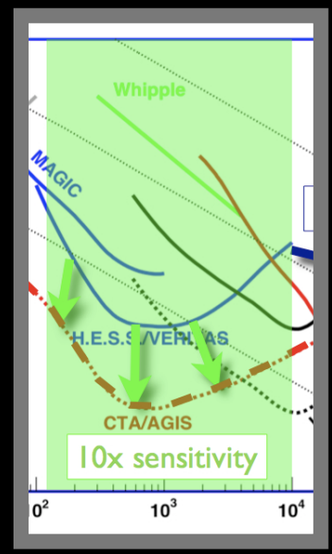
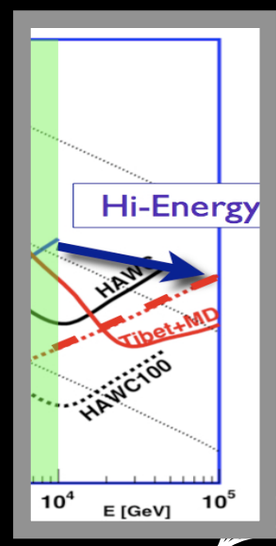


- Several Small Size Telescopes
  perform super-50 TeV detection
  - very simple construction
  - price should be small compared to full observatory
  - (maybe use only MST with larger FOV)



cta cherenkov telescope array

Site Selection

- Southern ca 100 M€, full energy coverage 10 GeV-some 10 TeV, good angular resolution, large FoV for galactic scans
- Northern ca 50 M€, optimized for extragalactic sources, moderate FoV and angular resolution
- From the point of view of efficient implementation, the sooner the better

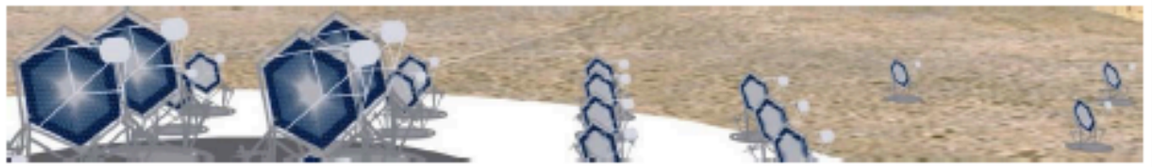
→ Converge quickly on 2 Northern candidate sites and 2 Southern candidate sites

- Optimize Sensitivity for given money

The CTA Project

Structure, ideas, schedule

On astro-ph:
arXiv:1008.3703



Design Concepts for the
Cherenkov Telescope Array
CTA

**An Advanced Facility for Ground-Based
High-Energy Gamma-Ray Astronomy**

The CTA Consortium

May 2010

The CTA Project

Structure, ideas, schedule

On astro-ph:
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- Partners:
  - HESS+MAGIC collaborations + European (all) + US AGIS + Japan + worldwide
  - ~130 institutes, ~25 countries (~ 700 scientists, 220 FTEs)
  - Regular meetings since 2007.
  - Project to be run as observatory

- Structure
  - Spokesperson: W. Hofmann (MPI-K, Heidelberg),
  - Co-spokesperson: M. Martinez (IFAE, Barcelona)
  - Work Packages:
    - Physics, MC, Telescope and Mirrors,
    - Focal Plane Instrumentation,
    - Electronics, etc.
  - 2010: “Horizontal” packages:
    - SST, MST, LST

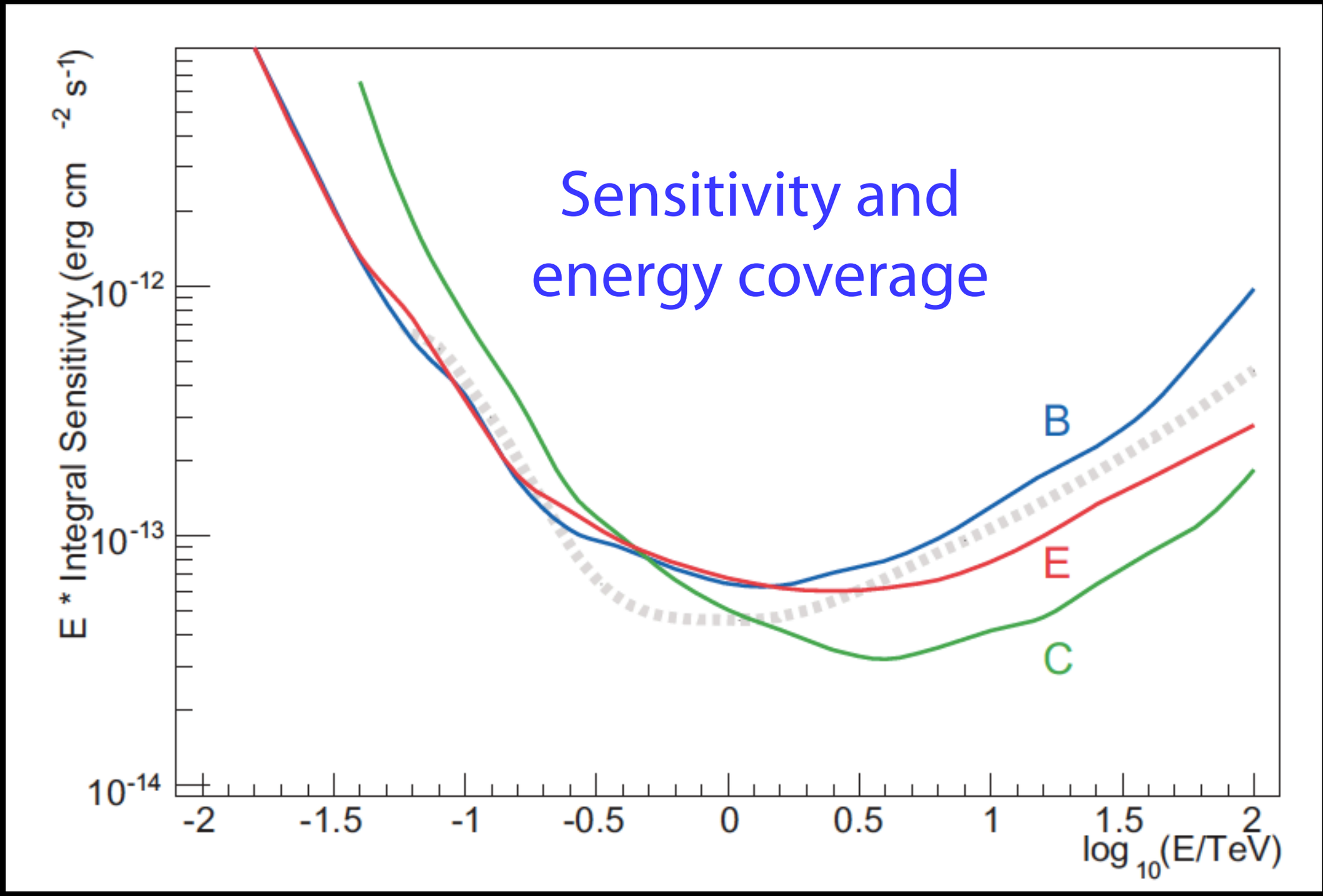
Design Concepts for the Cherenkov Telescope Array CTA

An Advanced Facility for Ground-Based High-Energy Gamma-Ray Astronomy

The CTA Consortium

May 2010

Basic message from MC: CTA works!



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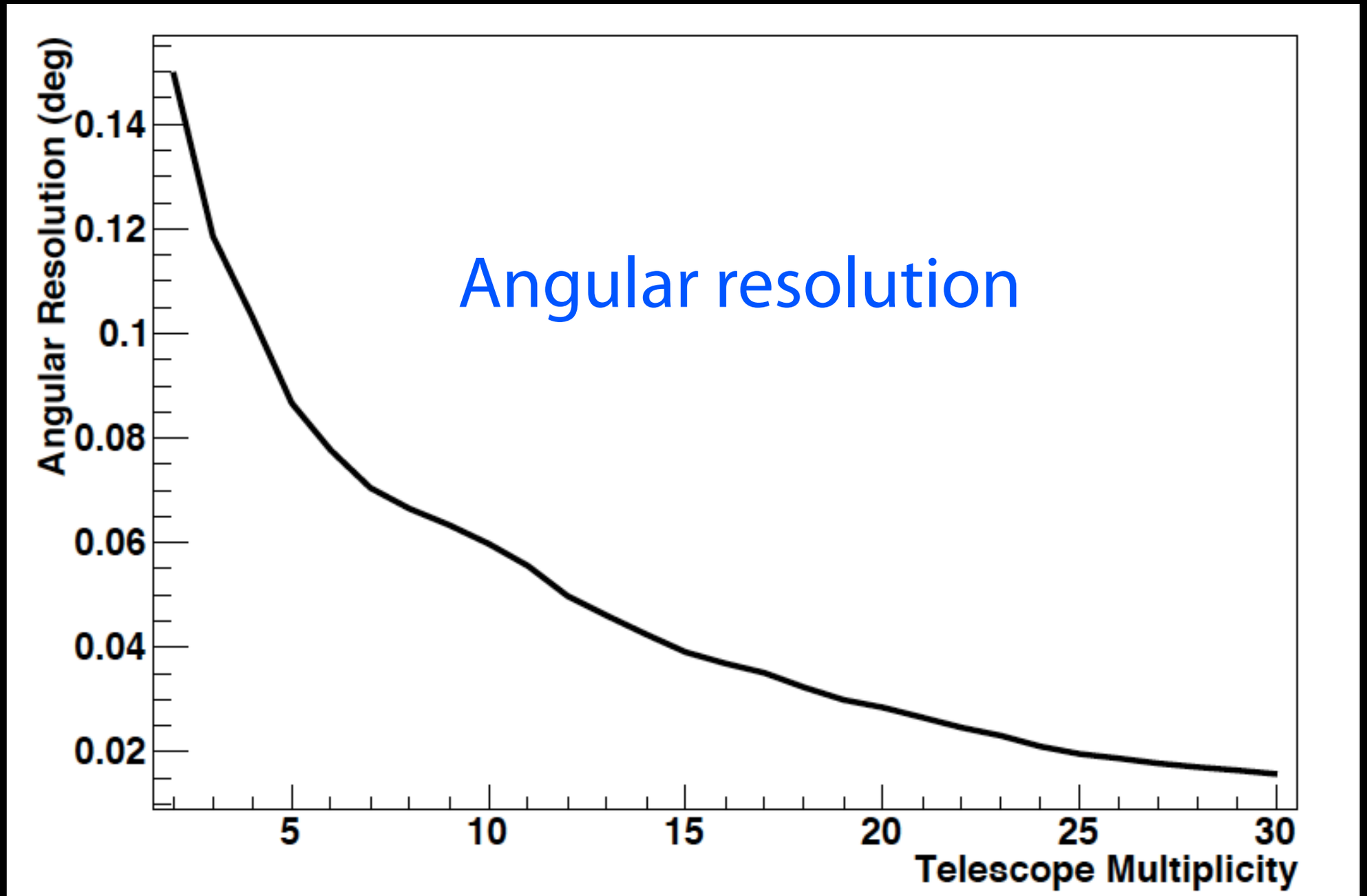
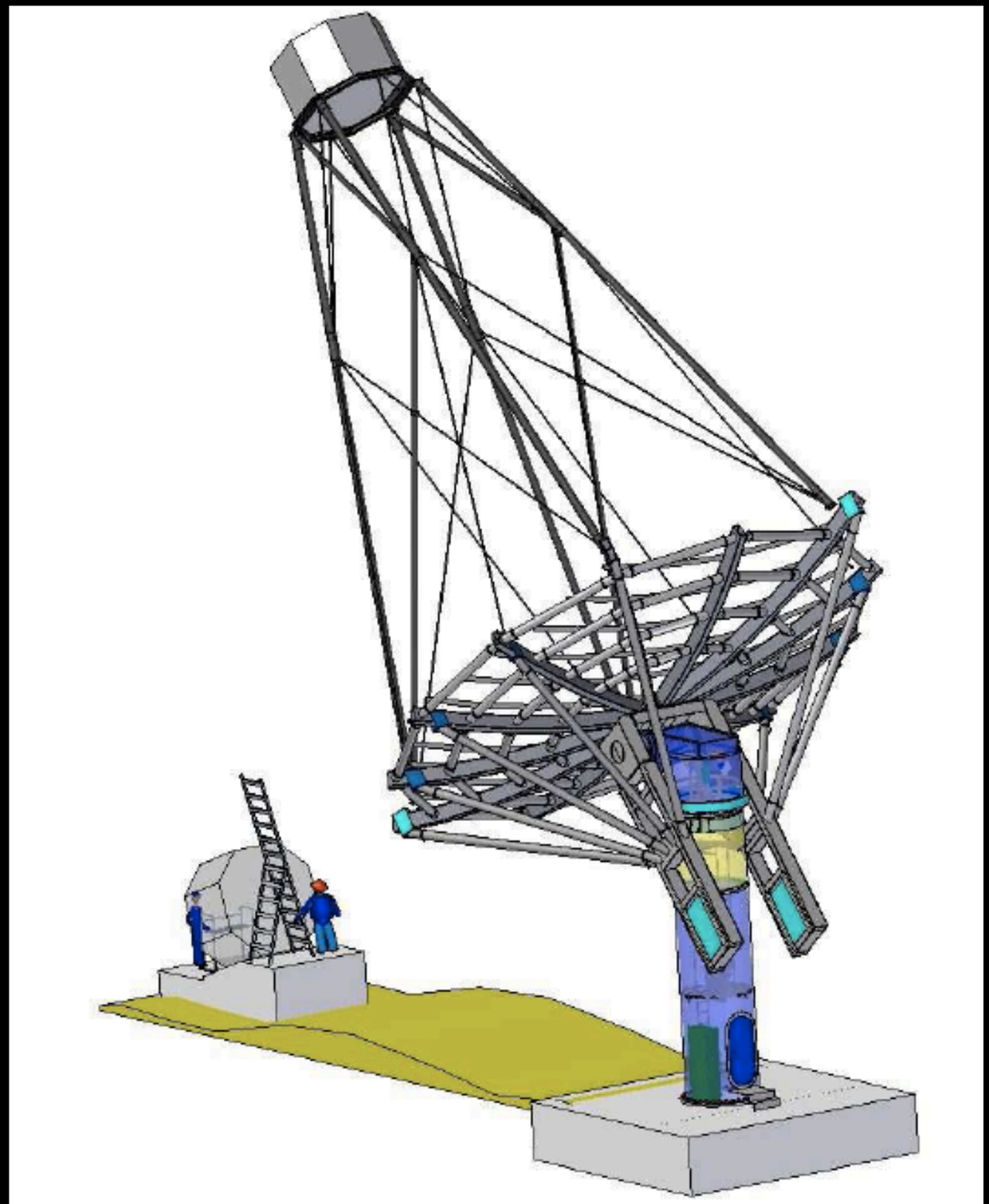


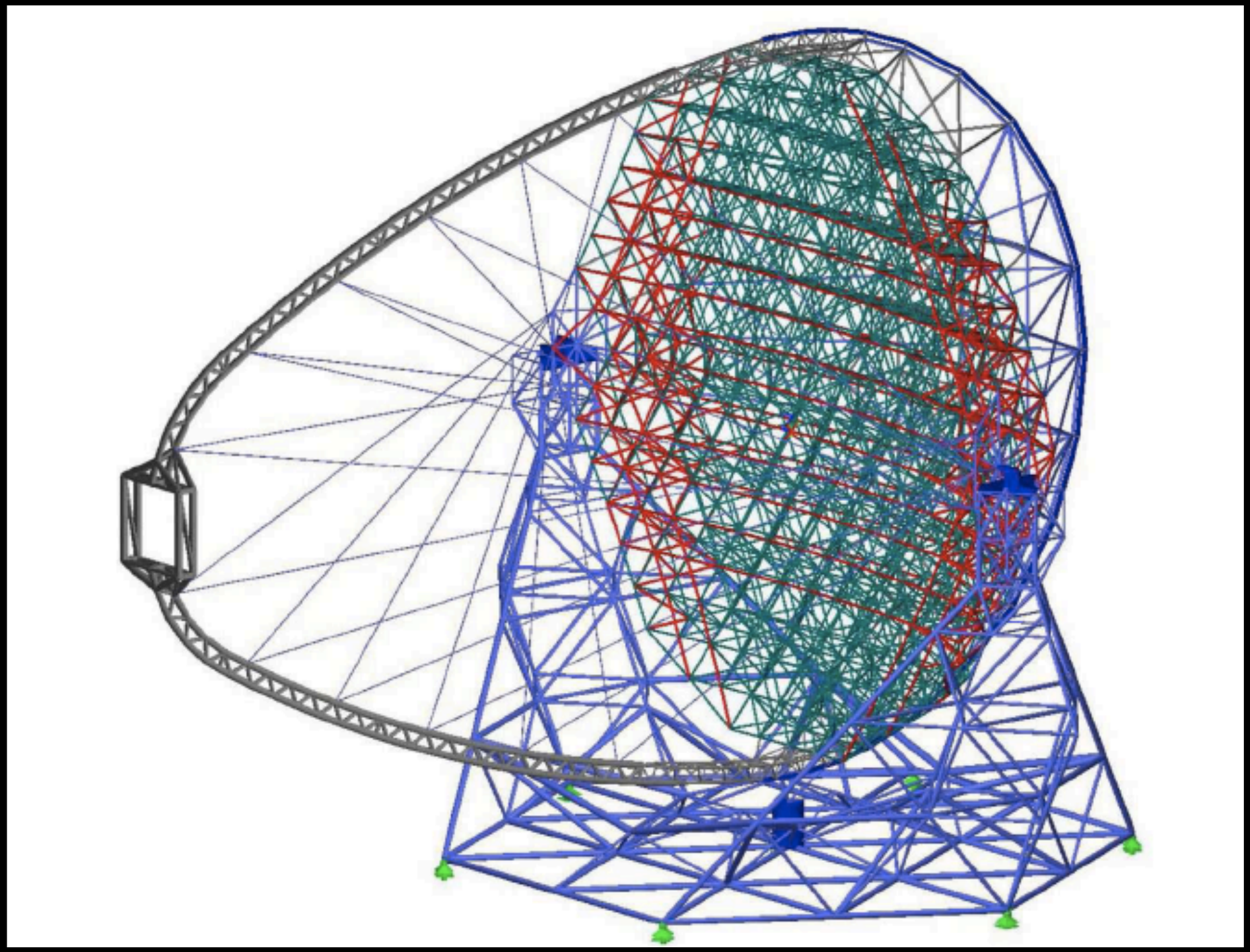
Telescope designs: 12m Telescope

MST
Example
DESY-Zeuthen
Design



Telescope designs: 23m Telescope

LST
MPI-P
Design



CTA Timeline

- 3 Year Design Study now succeeded by Preparatory Phase
- Prototyping planned for 2011/2
- Construction 2013...

FP7 DS application → ← "Kick-off": Barcelona, Jan 24-25

	06	07	08	09	10	11	12	13
Array layout								
Telescope design								
Component prototypes								
Telescope prototype								
Array construction								
Partial operation								

Design

Prototype

Array

Preparatory Phase started October 2010

↑ Concep. Design

↑ Detailed Design

Goals of Prep Phase

- Provide a technical design
- Provide site choices
- Provide organizational, legal, financial framework
- Provide reliable costs for construction and operation
- Secure funding
- Prepare science exploitation

Get agencies to sign!

Duration: Oct 2010 – Sept 2013

Budget: 5.2 M€

MPI contribution to CTA

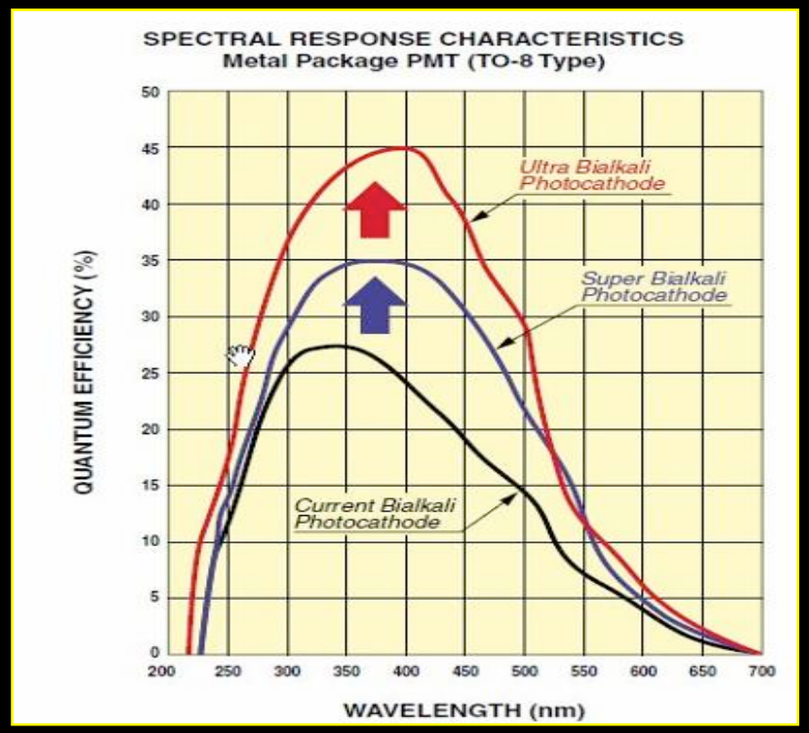
- The key input from MAGIC are the **low threshold energy** and **fast rotation**
  - Study of high-redshift AGNs (~several 100s) and GRBs (~10)
  - Galactic pulsars
  - Cosmology
  - Search for LIV and DM annihilation/decay
  - 10-100 GeV physics is very unique (Fermi: poor sensitivity) for testing fundamental physics and cosmology

- Contribution to Large Size Telescopes (LST)
  - **Our experience in MAGIC**
    - Design and construction of LST Structure
    - Design and construction of LST Cameras

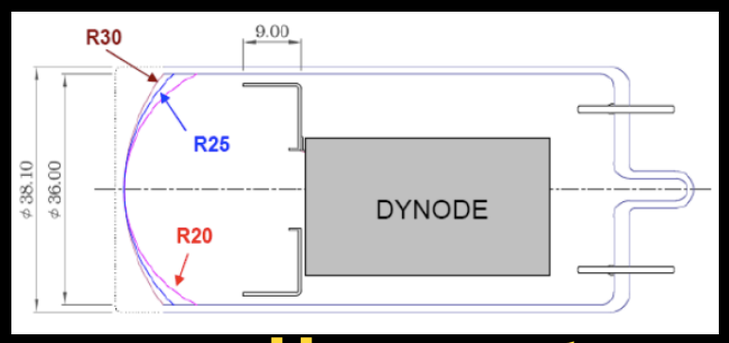
High QE photosensors development

CTA: 200k photosensors needed

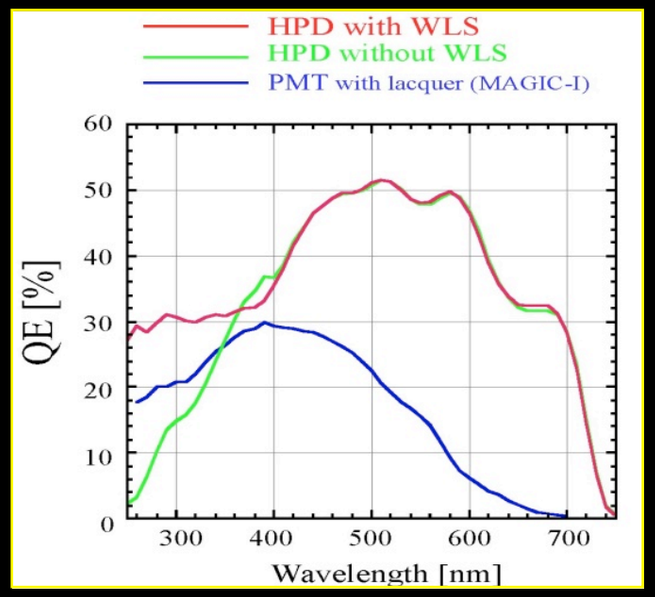
CTA-FPI WP leader R. Mirzoyan (MPI-P)



R9420 (QE=34%)

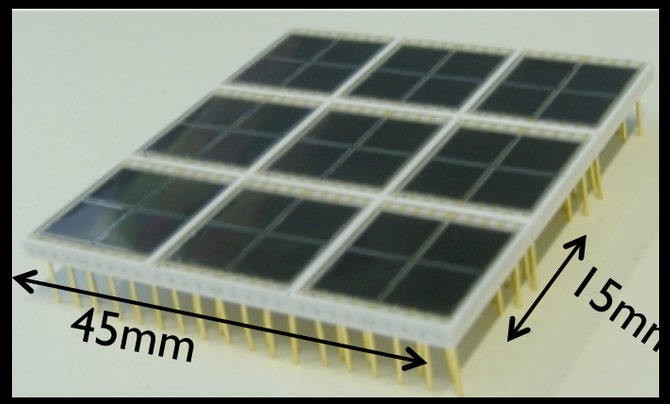


Hamamatsu
SBA 34% QE
==> 33% PDE

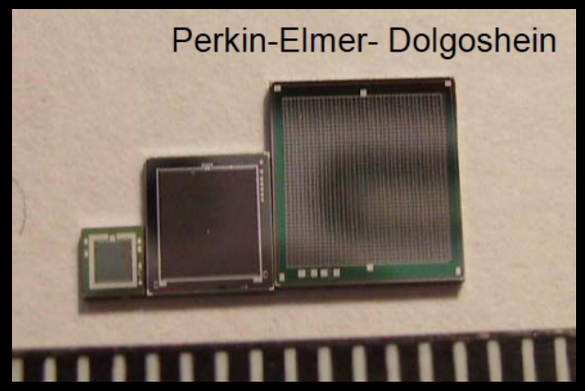


GaAsP HPD
(MPI & Hamamatsu):
50% PDE

Hamamatsu & MPI MPPC Array

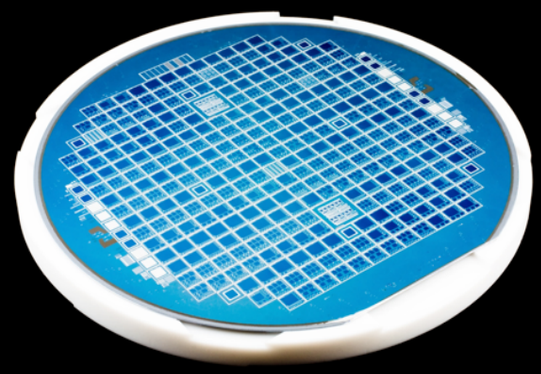


PDE~40%



Size 5x5 mm²

PDE~50%



MPI-HLL SiMPL

PDE~60%(target)

SiPM
About 60% effective PDE
will be realistic

MPI contribution to CTA

- Status of MAGIC
  - 2009: MAGIC-II is completed
  - 2009-2011: upgrade MAGIC-I (fully compatible camera with M-II)
  - 2010-2015: MAGIC next 5 years

- CTA is the next major step after MAGIC in VHE gamma-ray astronomy

- Tentative time schedule of CTA
  - 2010-2012: prototyping of MSTs
  - 2010-2011: detail design of LST
  - 2011-2014: prototyping of LST
  - 2013-2018: full construction

- **LST-SYS Coordinator:** M. Teshima, MPI-P
- **LST-STR Coordinator:** T. Schweizer, MPI-P
- LST-CAM Coordinator: O. Blanch, IFAE Barcelona

- 70 collaborators in CTA-LST work package

CTA-LST Key Participants

LST-STR: Structure and Optics

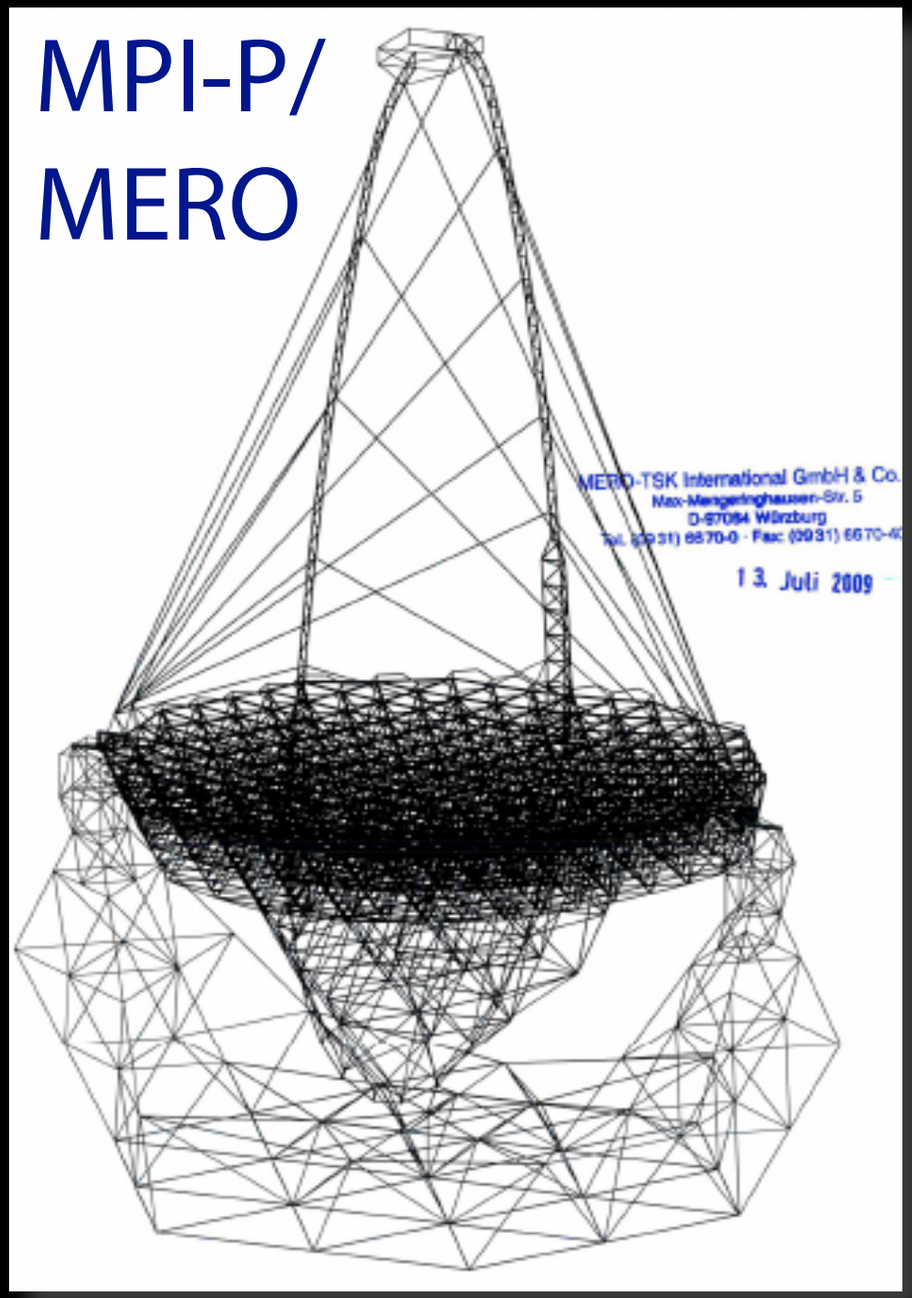
Telescope Structure	**MPP**, CEA
Telescope Bogeys	**MPP**, IFAE
Telescope Arch	LAPP, **MPP**
Telescope Drive	**MPP**, LAPP
Reflective Surface	INFN, Japan
Active Mrrror Control	ETH, U Zürich

LST-CAM: Camera

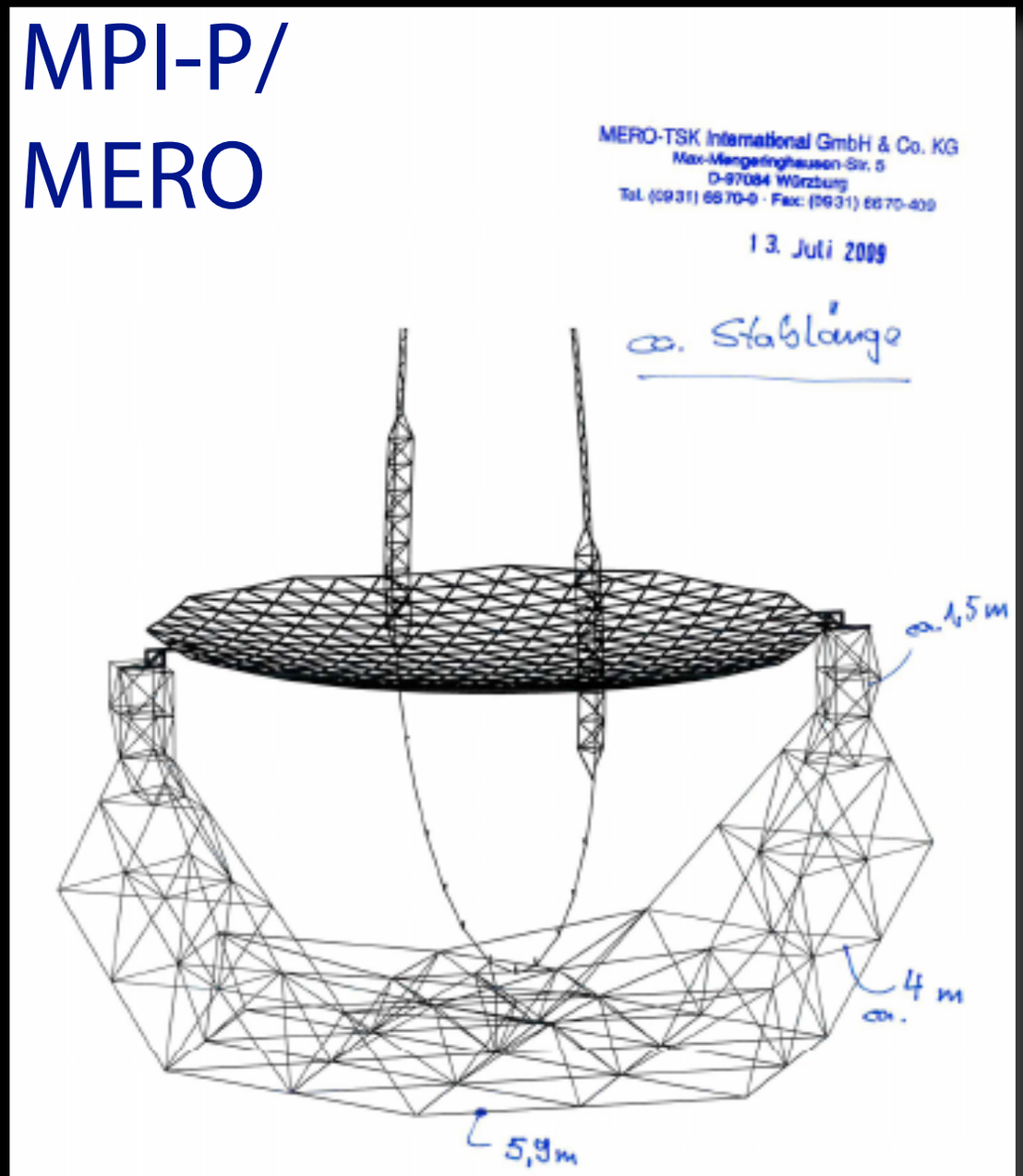
Camera Structure	**MPP**, IFAE
Cooling	**MPP**, CIEMAT?
FPI	**MPP**, IFAE, Japan
Light Concentrators	**MPP**, IN2P3
Readout	INFN, Japan, IN2P3
Trigger	IFAE, INFN

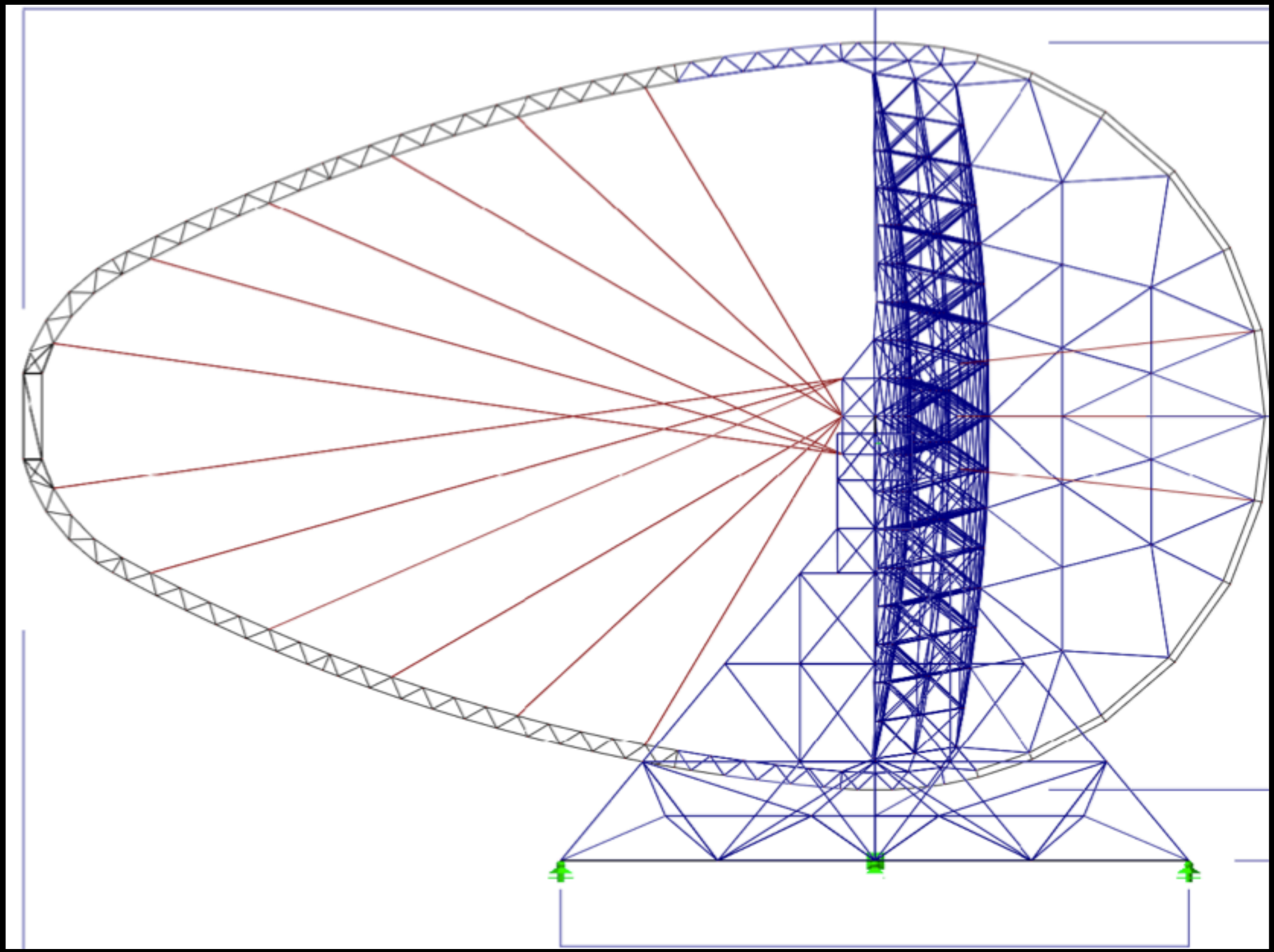
23m telescope design

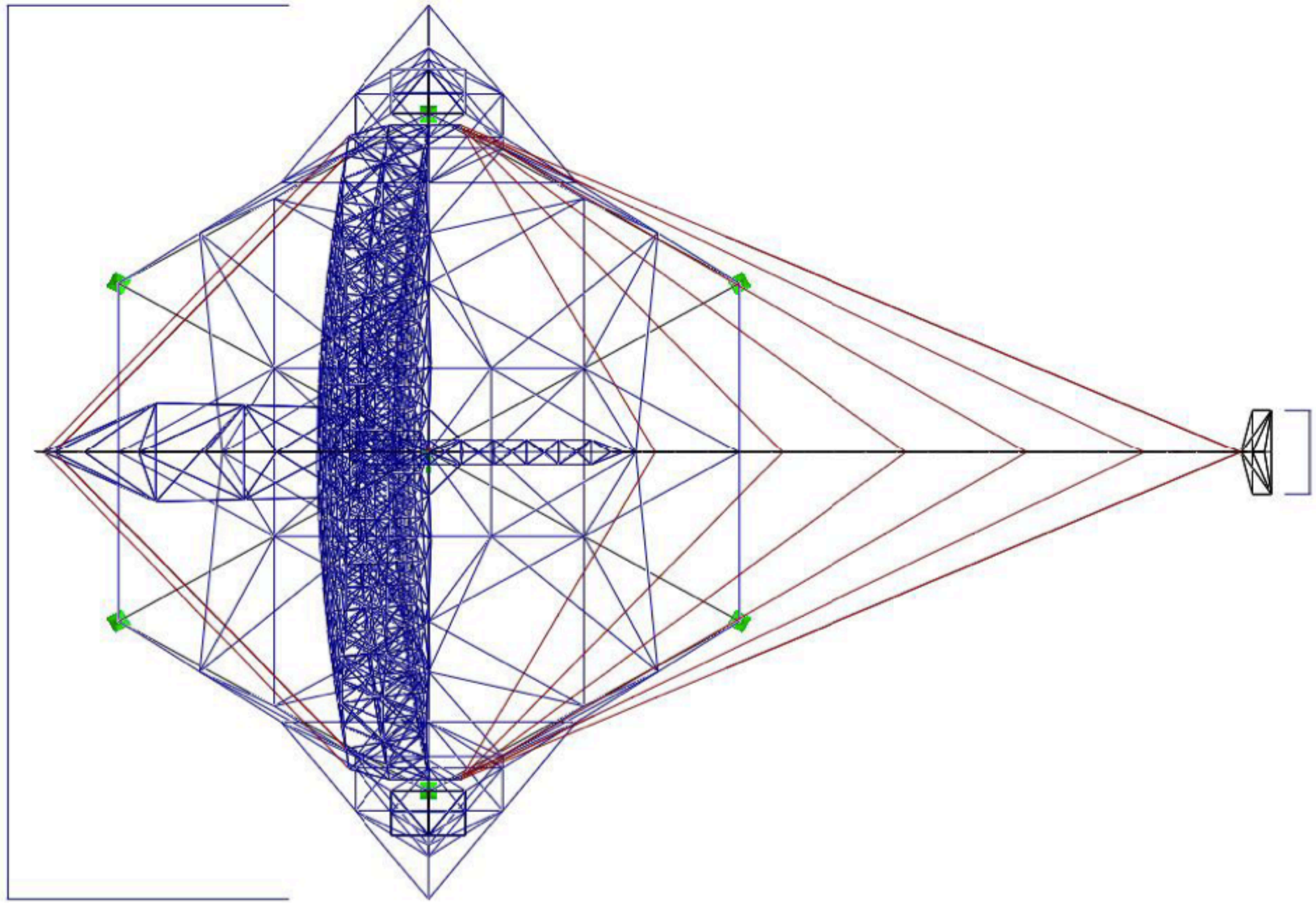
MPI-P/
MERO



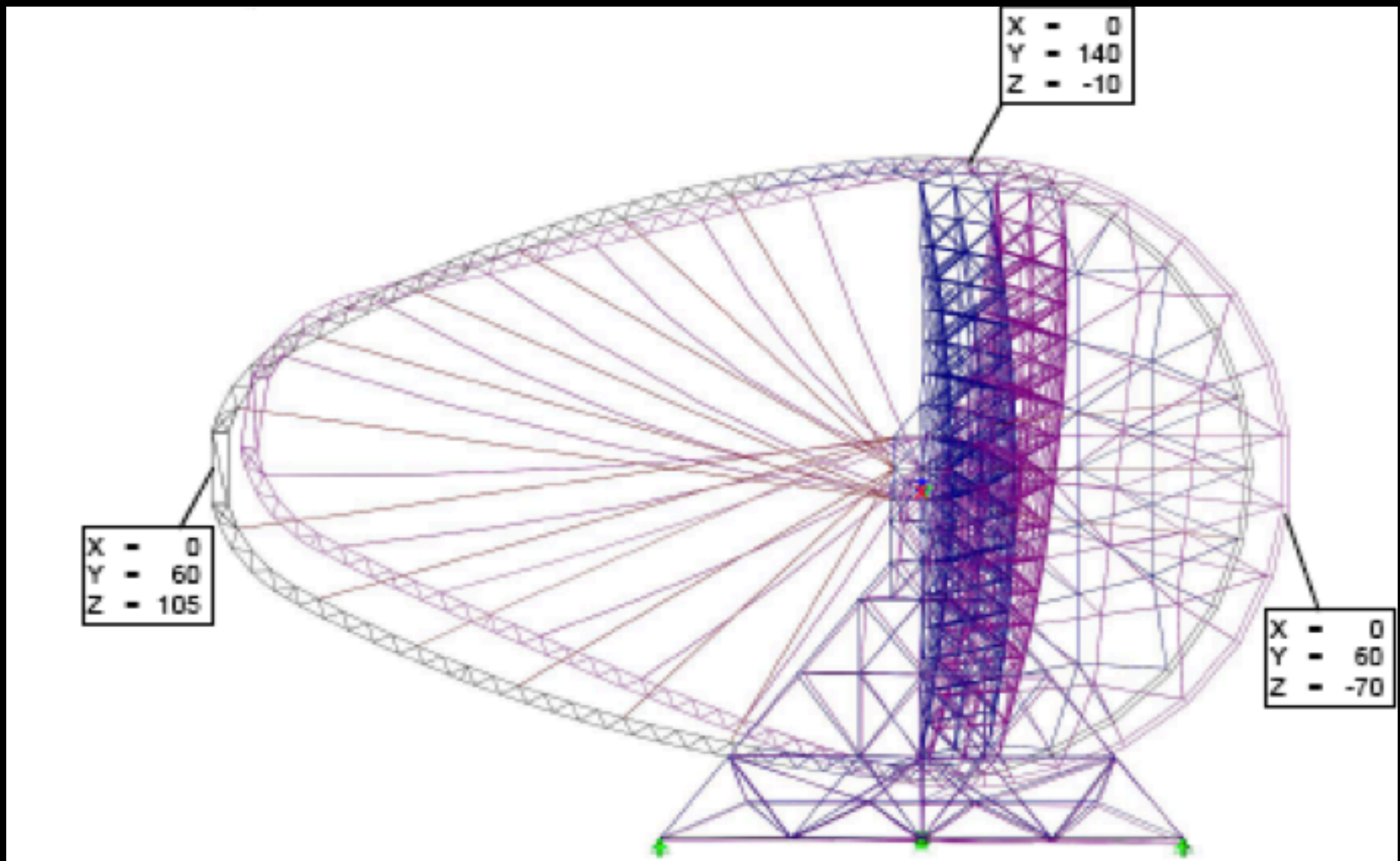
MPI-P/
MERO







Wind load studies: 160 km/h, 60 t



Summary

- In 4+ years from now,
  - CTA will open the era of precision gamma-ray astronomy
    - Galactic and extragalactic objects
  - CTA may answer long-standing questions on cosmic-rays:
    - Where galactic and extra-galactic CR are accelerated
    - How CR are accelerated
      (hadrons/leptons, jets, magnetic irregularities, etc.)
  - CTA may answer fundamental physics questions concerning
    - DM,
    - Lorentz invariance,
    - Universe transparency (EBL),
    - Cosmology

- For a new generation of IACTs, it is mandatory to:
  - Extend energy range from few tens of GeV to 100 TeV
  - Improve sensitivity and energy resolution
  - Larger FOV and better angular resolution
  - Operate as observatory